



ISS021E030638

Japanese Experiment Module-Exposed Facility (JEM-EF) attached payload for the International Space Station (ISS)

CATS-ISS

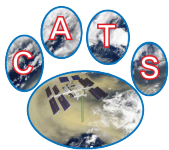
(Cloud-Aerosol Transport System for ISS)
Instrument Preliminary Design Review
September 20, 2011

Directed Opportunity

Payload Delivery Date: April 2013

Planned Launch Readiness Date: mid-2013

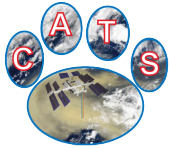




Agenda

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8:30 – 8:45	Intro & Introductions	Kirk Rhee	0:15
8:45 – 9:10	Programmatic overview	Matt McGill	0:25
9:15 – 9:30	Safety	Phillip Adkins	0:15
9:35 – 9:50	Science overview	Ellsworth Welton	0:15
9:55 – 11:05	Optics, lasers, detectors	Stan Scott	1:10
11:10 – 12:00	Mechanical/structural	Billy Mamakos	0:50
12:00 – 1:00	Working lunch		
12:30 – 1:15	Thermal	Paul Cleveland	0:45
1:20 – 1:45	Electrical	John Cavanaugh	0:25
1:50 – 2:30	Avionics	Fibertek	0:40
2:35 – 2:55	I&T and GSE	Matt or Stan	0:20
3:00 – 3:30	Conclude, discussions, review any actions	All	0:30

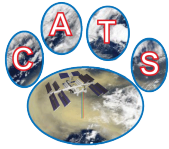


CATS-ISS Program Overview - 1

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- **The Cloud-Aerosol Transport System (CATS) instrument is a directed opportunity funded directly by SOMD.**
 - Payload Developer is GSFC
 - SOMD “customer” is Marybeth Edeen/JSC-OZ
- **Project was initiated in April 2011, 24-month schedule.**
- **The CATS project has three simultaneous goals:**
 - Provide long-term (6 months to 3 years) operational science from ISS
 - basic CPL configuration ensures success
 - Provide tech demo on-orbit
 - high rep rate laser
 - photon-counting detection
 - UV (355 nm) laser operation in space
 - Provide risk reduction for future Earth Science missions
 - UV (355 nm) laser operation in space [ACE, ASCENDS]
 - HSRL receiver concept [ACE]

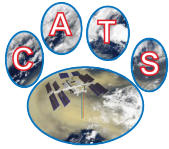




CATS-ISS Program Overview - 2

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- **The CATS instrument is fixed-price.**
 - C.S. FTE is: FY11 – 1.39; FY12 – 3.74; FY13 – 2.87
 - budget is: FY11 - \$7.457M; FY12 - \$2.785M; FY13 - \$1.625M
(includes 10% contingency)
- **CATS is not a “business as usual” project.**
 - not a flight mission – it is an attached payload (think Hitchhiker) launched as cargo.
 - intended as a pathfinder for quick turn-around, low-cost payloads, rather akin to Hitchhiker payloads.
 - being used as a pathfinder for U.S. attached payloads for ISS (only one other U.S. payload, it is non-NASA).
 - being used as a forcing function for Space-X payload launches.
 - funded by SOMD, it is essentially “free” science for SMD – from a science aspect, we get to make it what we want (or can).
 - working with HQ to define a ROSES call for post-launch science.



Mission Success Criteria

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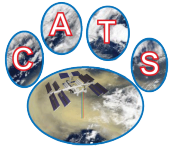
- From JSC/ISS (3/18/2011):

“The responsibility to generate and verify functional requirements (science requirements) of what the CATS payload shall do is up to your team.

General guidance from the ISS program is that

- the CATS payload is an attached payload with no flight reliability requirements. The goal of the CATS payload should be minimum 6 month operation, with maximum 3 year operation,
- the CATS payload should meet science objectives that both increase readiness for future flight missions and provide operational data related to the phenomenon you are measuring.”

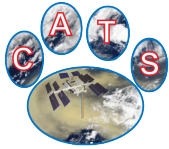
This customer guidance is consistent with the funding level. CATS-ISS is a low-cost, streamlined project.



Project-level Requirements

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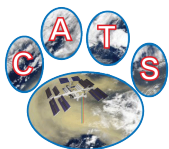
1. Develop Cloud-Aerosol Transport System (CATS) instrument for deployment to the ISS.
2. CATS shall be an attached payload for the JEM-EF (slot #4).
3. Launch vehicle shall be H-II Transfer Vehicle (HTV) or Space-X (TBD, current manifest is Sx6).
4. CATS shall not harm ISS or the launch vehicle.
5. CATS shall be designed to operate minimum 6 months, with goal of 3 years and option to extend to 5 years (hardware to be certified to 5 years for structural integrity).



Mission Concept/Design

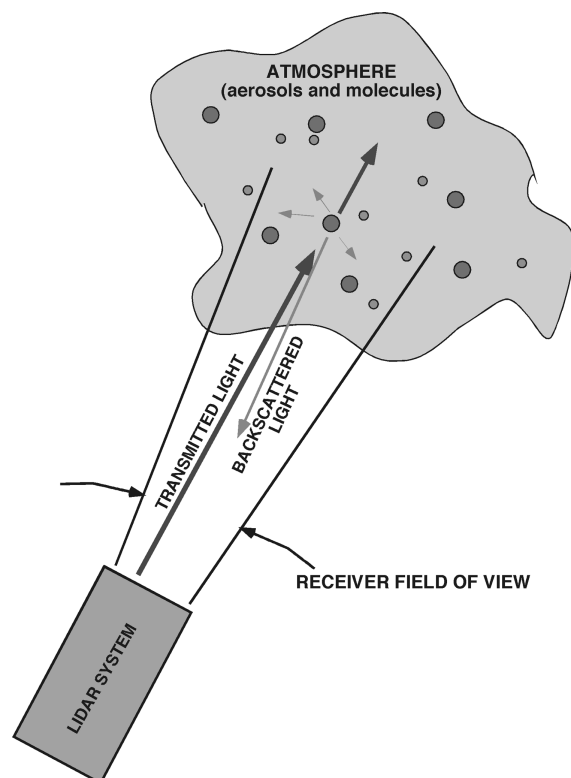
7

- Target Launch Date: mid-2013
- Orbit parameters: ISS orbit, 405 km, approx. 51 ° inclination.
- Instrument
 - Lidar, multi-wavelength (1064, 532, 355 nm)
 - Mass: < 500 kg
 - Power: 1200W
 - Data rate: ~ 2 Mbits/second via HRDL
- Launch vehicle options: TBD by JSC, either HTV or Space-X
- Mission Margins:
 - ISS allotment for JEM-EF attached payloads are 500 kg, <3 kW, and HRDL FDDI data downlink option.



Instrument Overview: How Lidar Works

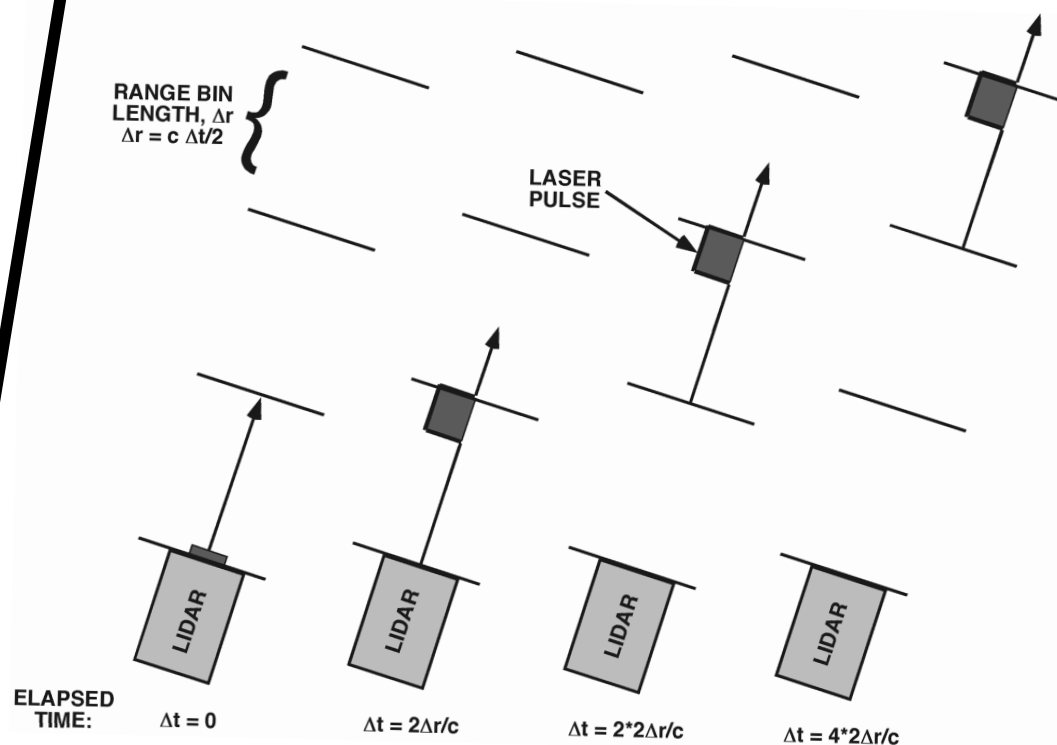
8



Basic concept of lidar remote sensing.

Transmitted laser light scatters from particles and molecules, is collected by a telescope.

Lidar “works” because the speed of light is known, and constant.

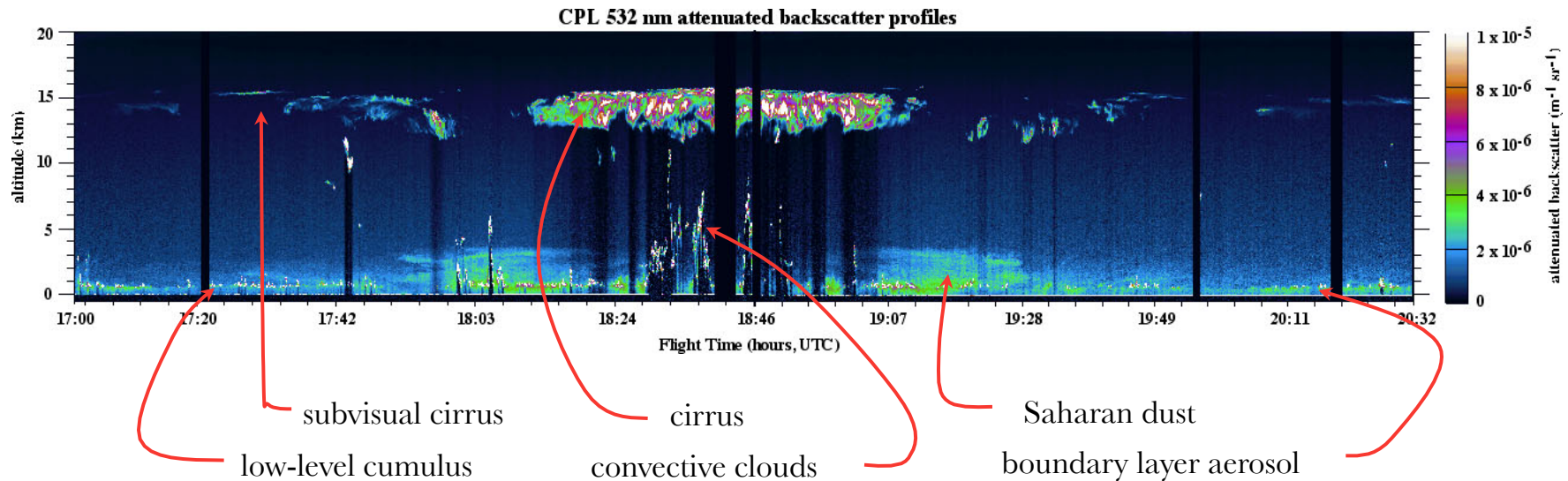


Entire profile is captured from each laser pulse.



Lidar (backscatter) Data Example

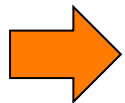
9



Lidar profiling generates a time-height cross-section of the atmosphere, revealing cloud and aerosol structure.

Multiple cloud/layer features can be measured, *up to the limit of signal attenuation* (O.D. 3-4).

From this data we derive layer boundaries, optical depth, extinction, and depolarization, and at least a coarse discrimination of aerosol type (e.g., smoke, dust, pollution). However, backscatter lidar results in under-determined set of equations and assumption must be made to separate aerosol-scattered signal from molecular-scattered signal.



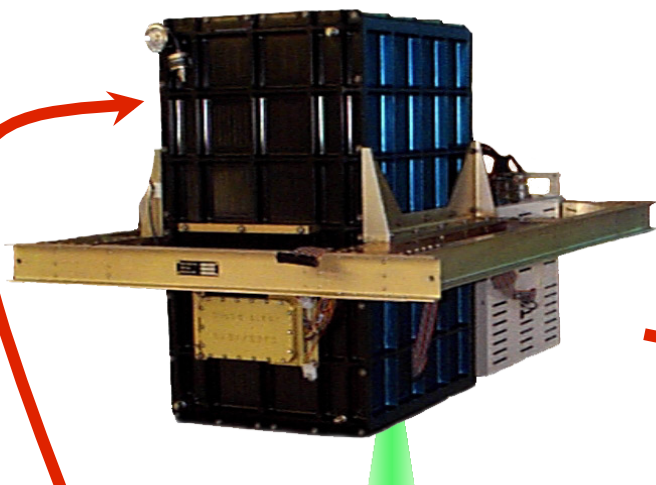
We have long history with backscatter lidar, the instrument concept is well understood. The long-term operational science aspect of the CATS mission is met by this type of measurement.



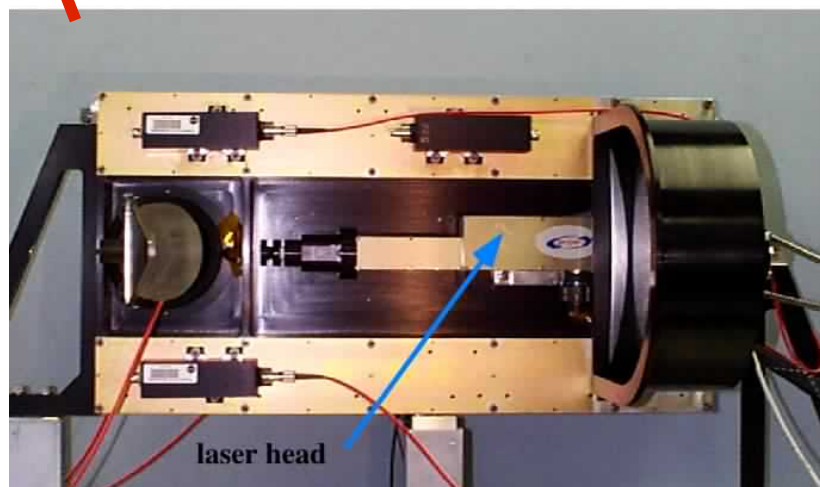
Heritage: the Cloud Physics Lidar

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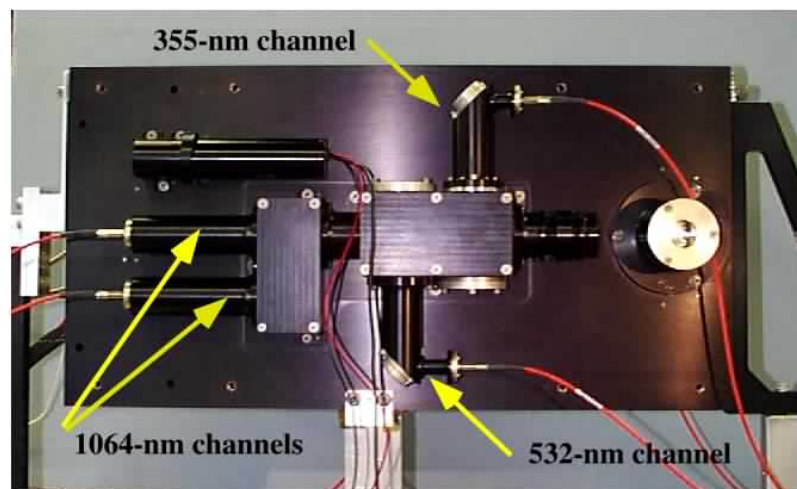
CPL is a self-contained, autonomous backscatter lidar



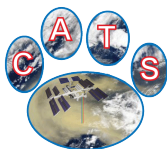
a)



b)



The CPL web site is: <http://cpl.gsfc.nasa.gov>



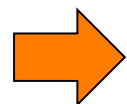
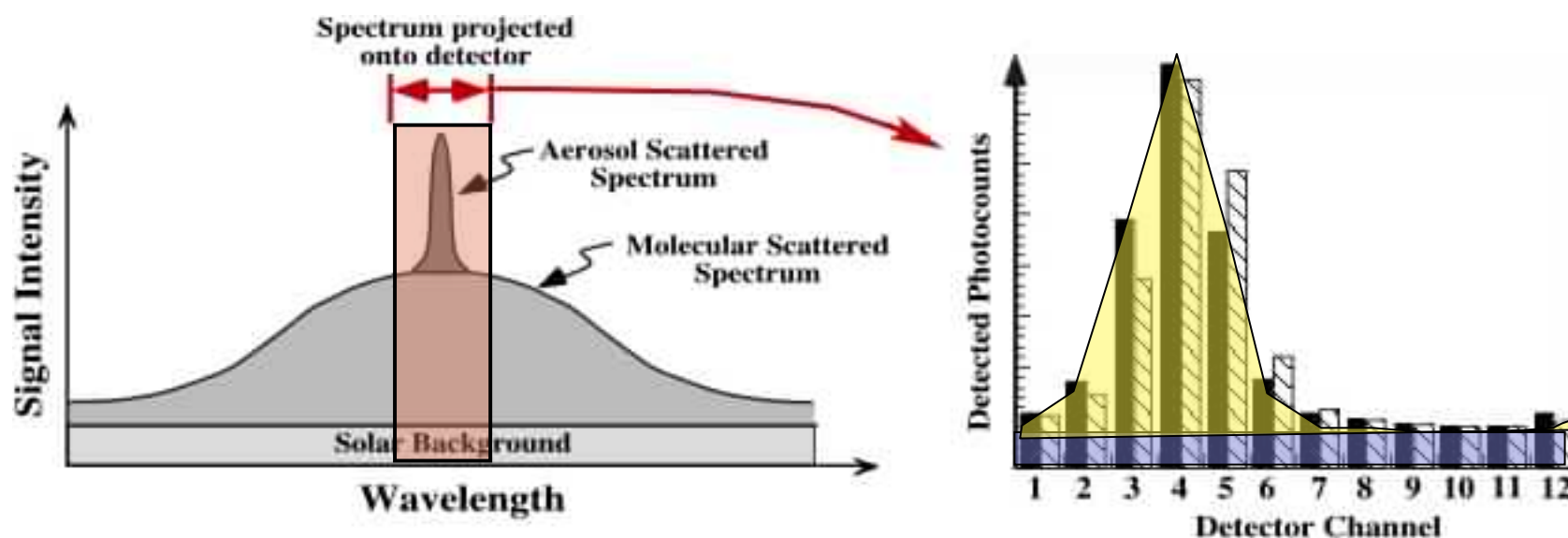
Lidar (HSRL) Concept

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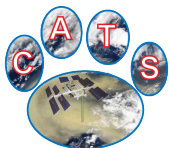
High Spectral Resolution Lidar (HSRL) is a method used to isolate aerosol-scattered light from molecular-scattered light, thereby permitting unambiguous determination of aerosol extinction.

Requires high-fidelity laser performance, more complex optical receiver.

Our approach uses a Fabry-Perot interferometer to reject most of the molecular-scattered light. Using a multi-element detector, the measured signal can be decomposed into aerosol and molecular components.

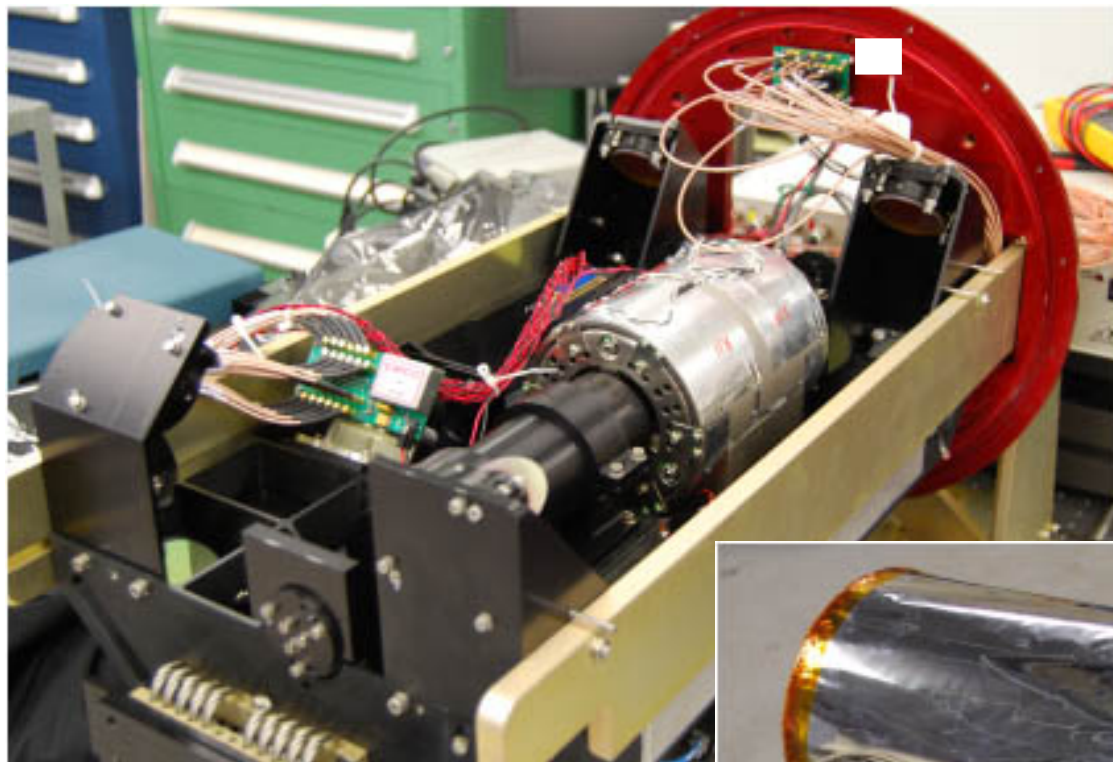


HSRL has not been done in space before. The CATS instrument provides tech demo and risk reduction for future Earth Science missions.



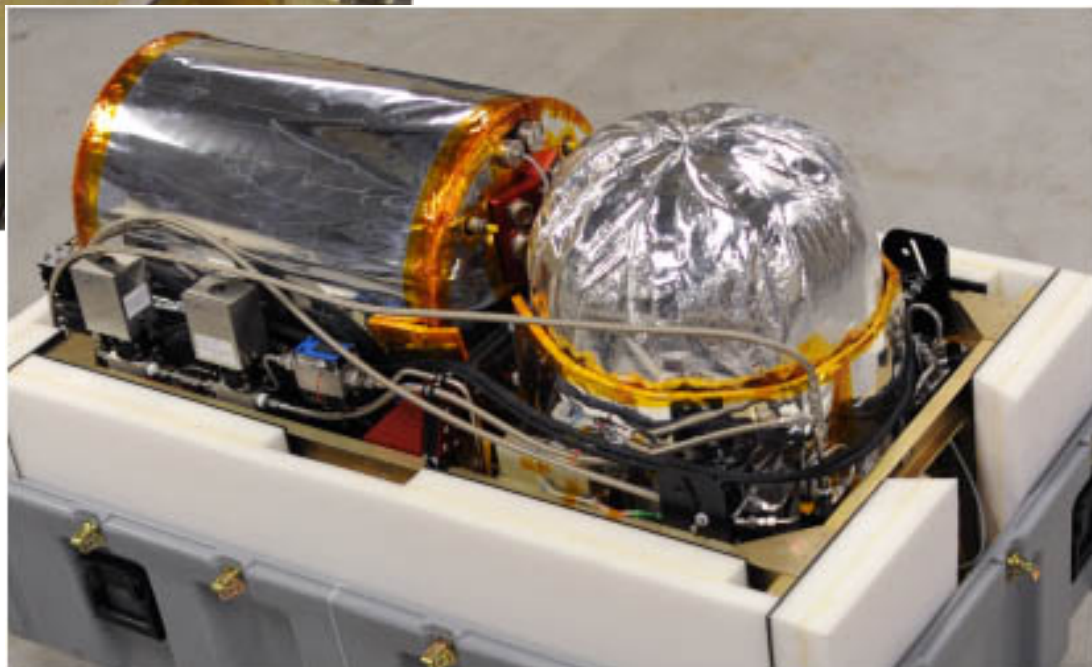
Heritage: Airborne CATS

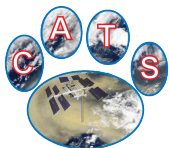
12



HSRL receiver subsystem,
will be used in CATS-ISS

Complete instrument, ready
for aircraft installation

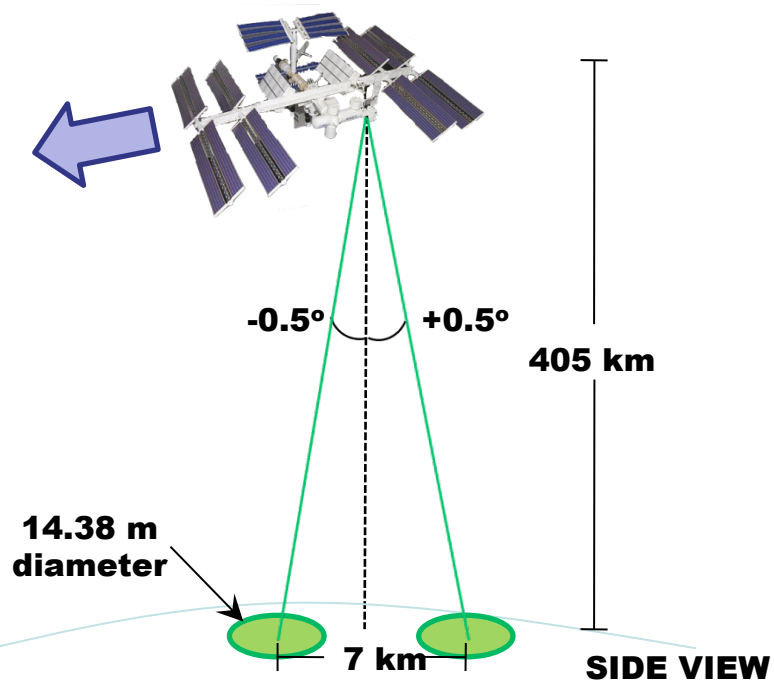




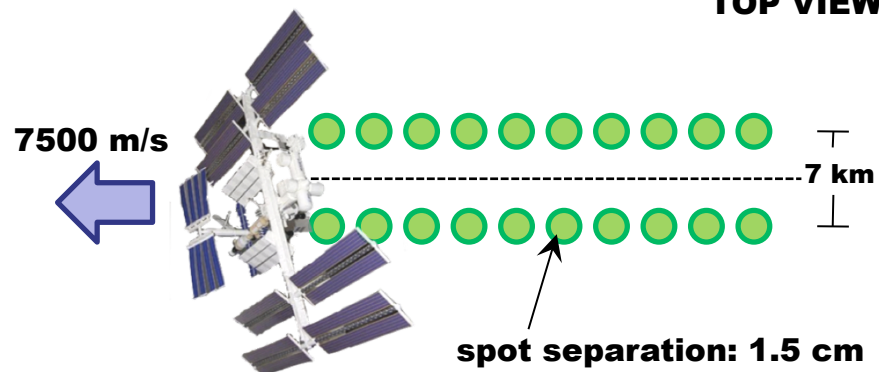
Geometry and Operating Modes

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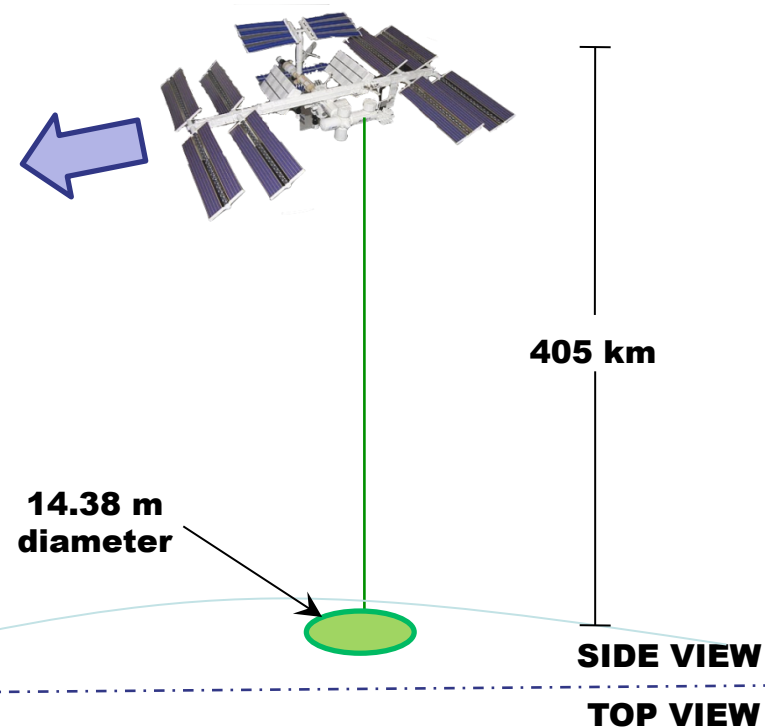
Laser #1 Mode



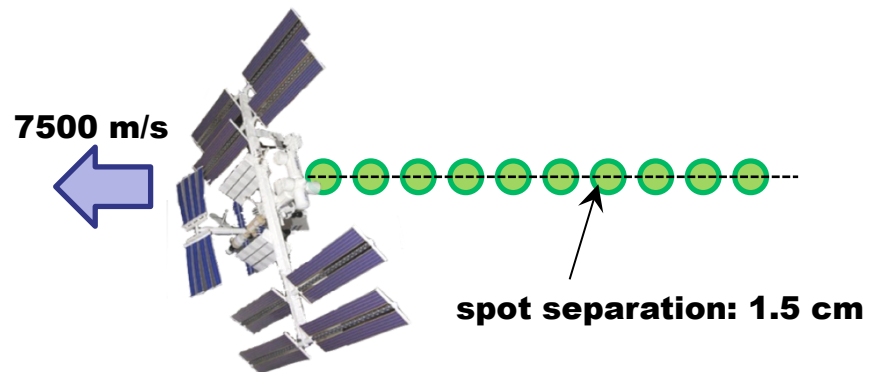
TOP VIEW

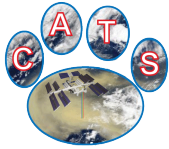


Laser #2a,b Modes



TOP VIEW

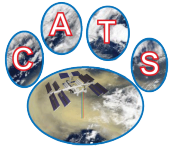




Operations

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- CATS-ISS payload will mount to JEM-EF slot #4.
- Although the CATS payload is designed to be safe for Extra Vehicular Activity (EVA) operations, there is no planned use of EVA personnel.
- Robotic operations will be required to remove the payload from the launch vehicle and deliver it to the JEM-EF (will be different procedure depending on which launch vehicle).
- On-orbit operations will be conducted through ground control only using only real-time commands.



Roles and Responsibilities

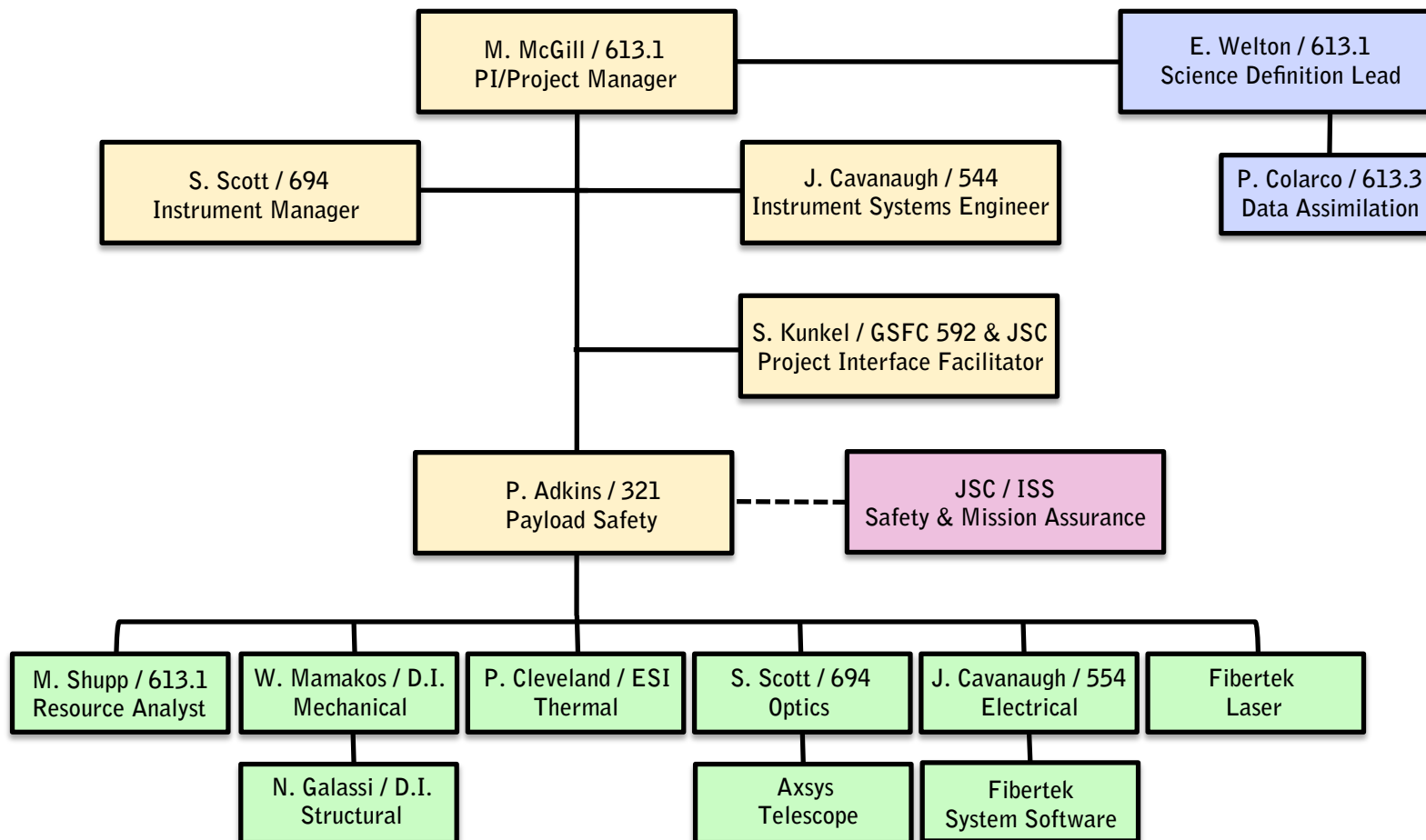
15

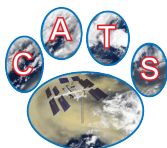
- CATS is a PI-led project. The PI is Dr. Matthew McGill / GSFC 613.1.
- Science aspects of the project will be based at GSFC, with Dr. Ellsworth Welton / GSFC 613.1 acting as Science Definition Lead.
- JSC/ISS is authority for safety; CATS team to identify and verify safety compliance (similar to Hitchhiker).
- Certification of Flight Readiness (COFR) is required for the payload. From Marybeth Edeen, “You only have to CoFR that you won’t break ISS. Your CoFR is to us, not through GSFC. That is how everyone else does it.”
- The payload is a single sensor and will be developed and assembled in-house. Environmental testing will be conducted out-of-house at contract facilities.
 - Fibertek, Inc. will provide the laser as a Phase-3 SBIR contract.
 - Design Interface, Inc. (W. Mamakos) will provide mechanical support through the SESDA-II contract.
 - Electrical/data system will be provided by Fibertek, Inc.
- Payload will be delivered to launch site for launch (HTV or Dragon).



CATS-ISS Organizational Chart

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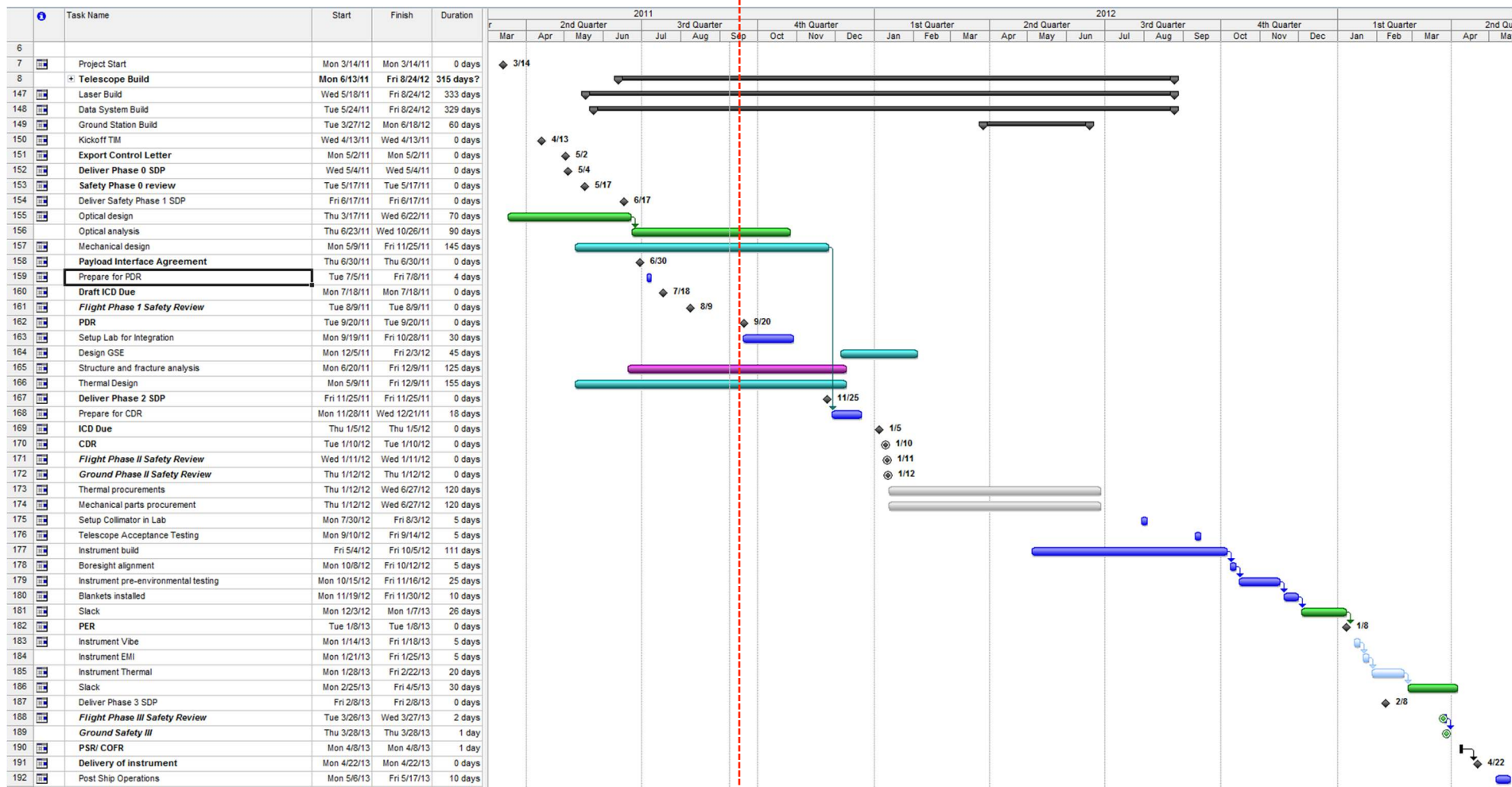


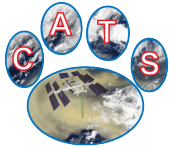


CATS-ISS Project Schedule

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Schedule is driven by April 2013 payload delivery date





Scope of Review

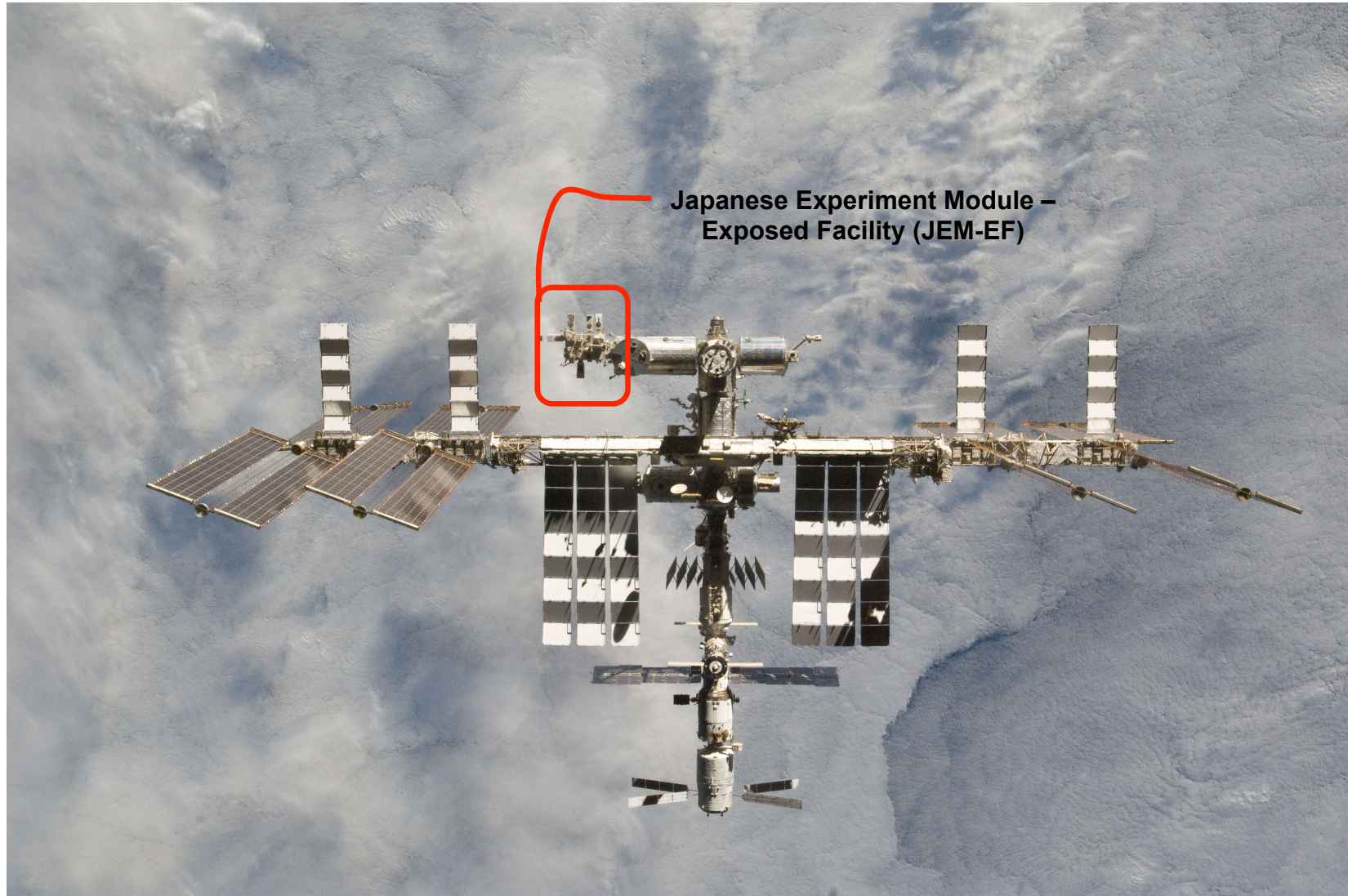
18

- This review is an instrument PDR (iPDR). We are only reviewing what's "inside the box."
- Safety is not covered in this review. The authority for safety is JSC's Payload Safety Review Panel (PSRP).
 - To-date the Project has successfully passed the Phase-0 safety review (May 17) and Phase-1 safety review (Aug 9-10).
- ISS interfaces are not covered in this review. An interfaces PDR at JSC on August 10 covered the ISS mechanical, electrical, thermal, and C&DH interfaces.
 - Following slides give a brief overview of the ISS interfaces, but that is the extent of coverage in this review.
- We are not reviewing C&DH. C&DH is dictated by ISS (through MSFC).
- We are not reviewing the laser architecture. Laser is treated as a "black box" with interfaces in the appropriate disciplines.
- Science justification will be addressed. However, because of the way this project came about we define our own science requirements, which is still on-going. Bottom line: the payload will do what it can do consistent with cost and schedule AND consistent with ISS safety protocols.

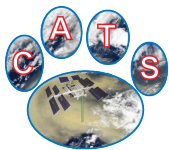


ISS Interfaces - 1

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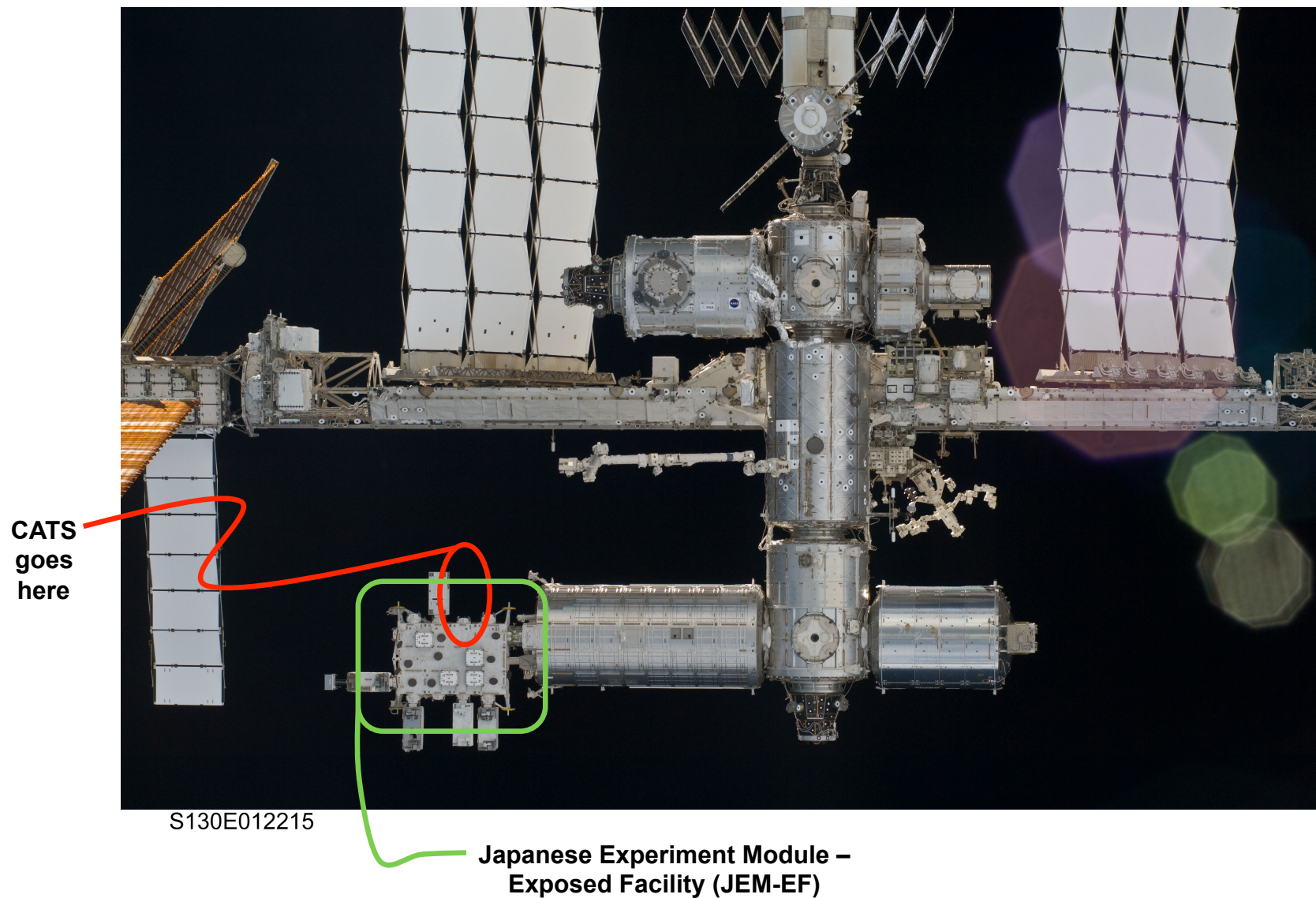


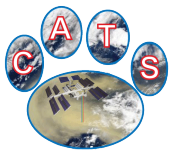
S133E010397



ISS Interfaces - 2

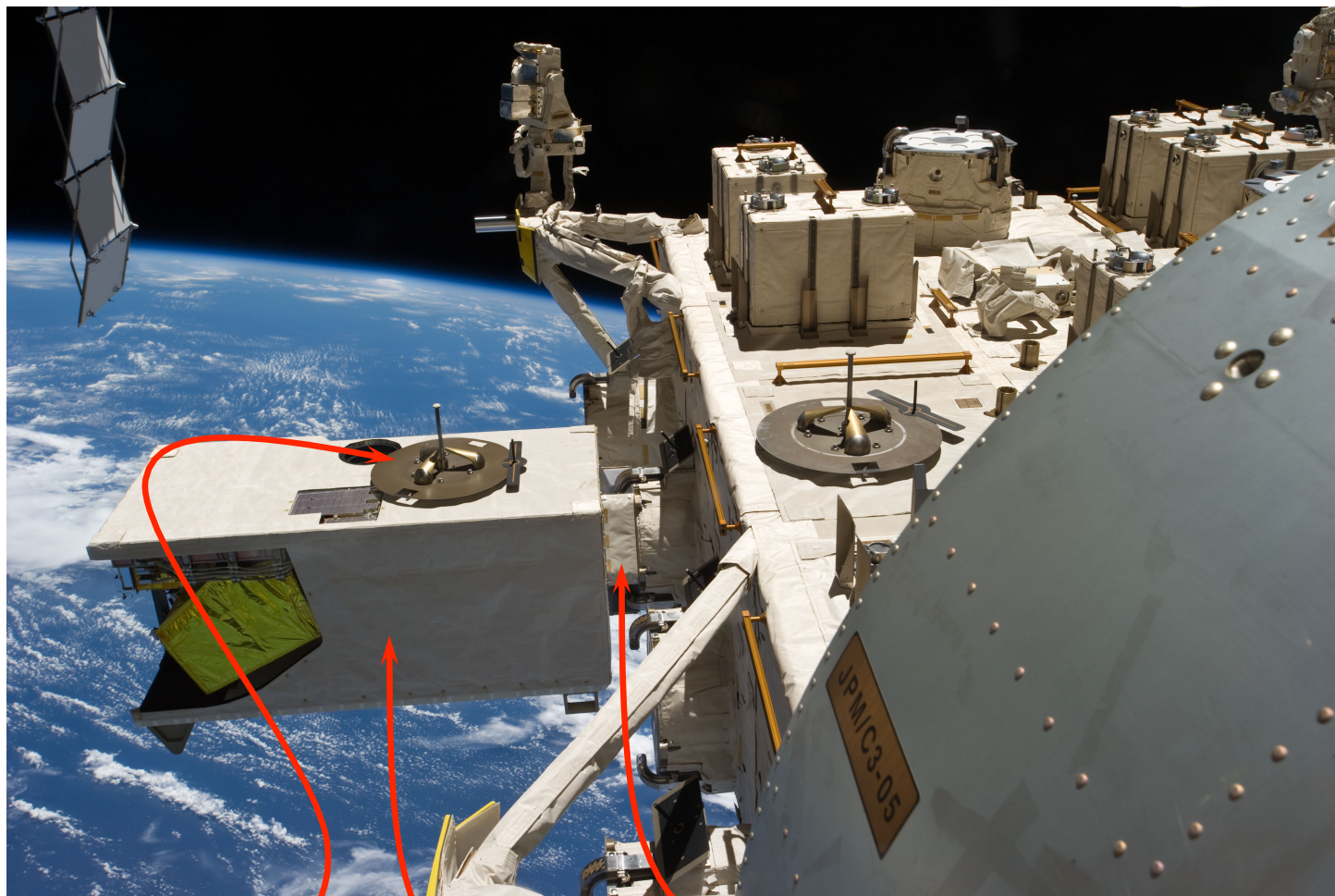
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ISS Interfaces - 3

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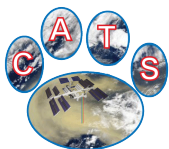


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grapple fixture

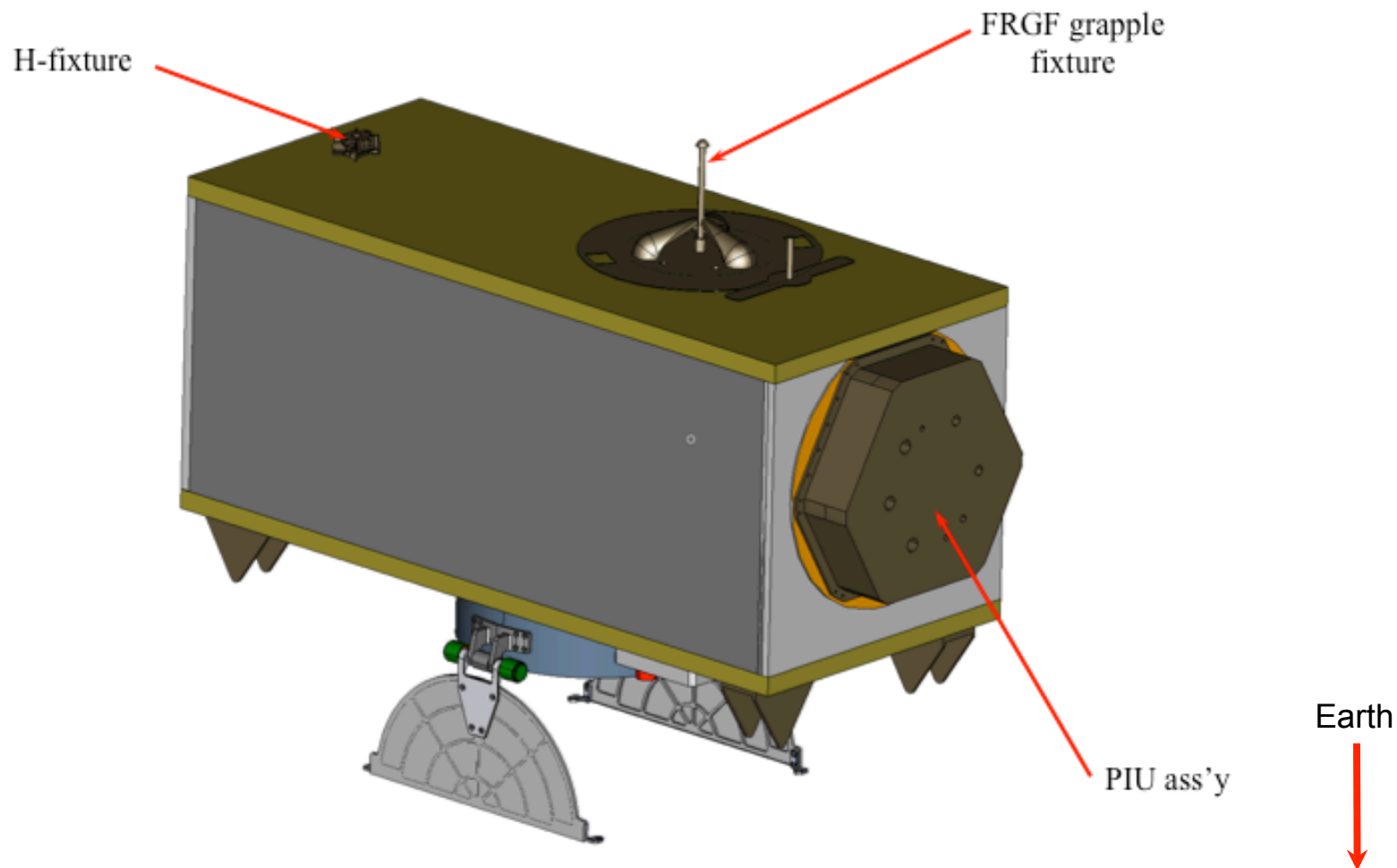
Payload Interface Unit (PIU)

JEM-EF attached payload



Payload to ISS Interfaces

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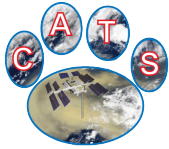
Standard JEM-EF payload volume: 1.855 x 0.800 x 1.299 m.

Total payload height is 51 inches including the 12 inches of protrusion required for the grapple fixture, per NASDA-ESPC-2857(rev C, part 2, vol 2), Figure 3.3.1.1.1-2.



Safety

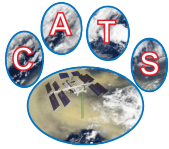
Phillip Adkins
GSFC Code 321



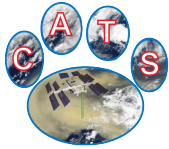
Safety Process and Requirements

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- **JSC Safety Process (Review and Approval via JSC Payload Safety Review Panel)**
- **Safety Requirements Documents**
 - **SSP 51700 “Payload Safety Policy and Requirements for the International Space Station”**
 - **SSP 30599 “Safety Review Process”**
 - **NSTS/ISS 18798 “Interpretations of NSTS/ISS Payload Safety Requirements”**



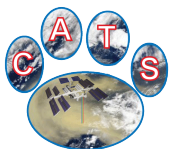
- Six Flight Safety Hazard Reports
 - CATS-ISS-STD-001: Standard hazards
 - CATS-ISS-002: Structural failure
 - CATS-ISS-003: Rupture/explosion of pressure system
 - CATS-ISS-004: Exposure to non-ionizing radiation
 - CATS-ISS-005: CATS payload electrical hazards
 - CATS-ISS-006: EVA contact hazards
- Phase I Flight Safety Review (8/9-10/11)
 - All Hazard Reports Signed at Phase I
- Phase II Flight Safety Review
 - Currently scheduled for January 2012



Science Overview

Judd Welton
Matthew McGill
John Yorks

Modeling contributions from:
Peter Colarco, Arlindo da Silva, and Virginie Buchard

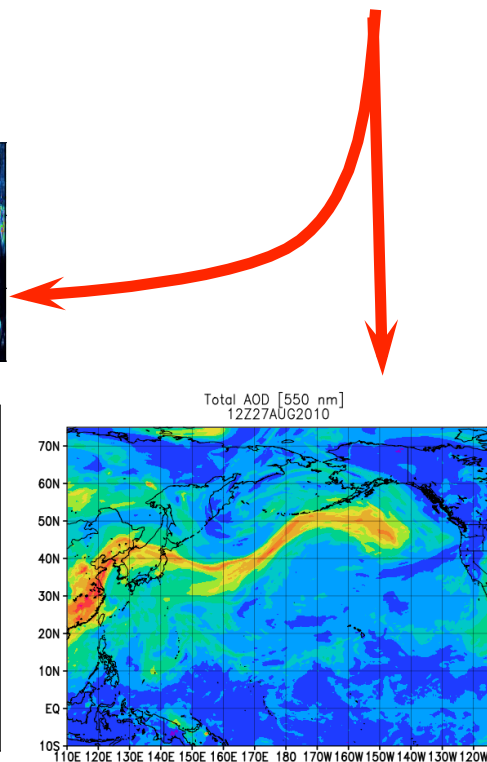
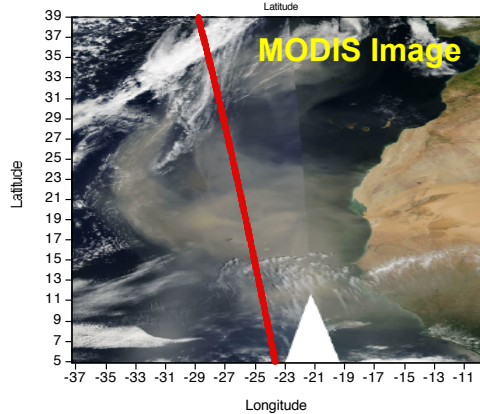
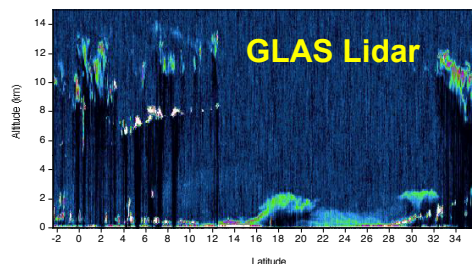


CATS-ISS Science Overview

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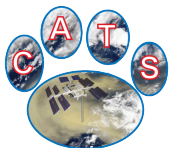
Aerosol and Cloud Properties



Aerosol Modeling

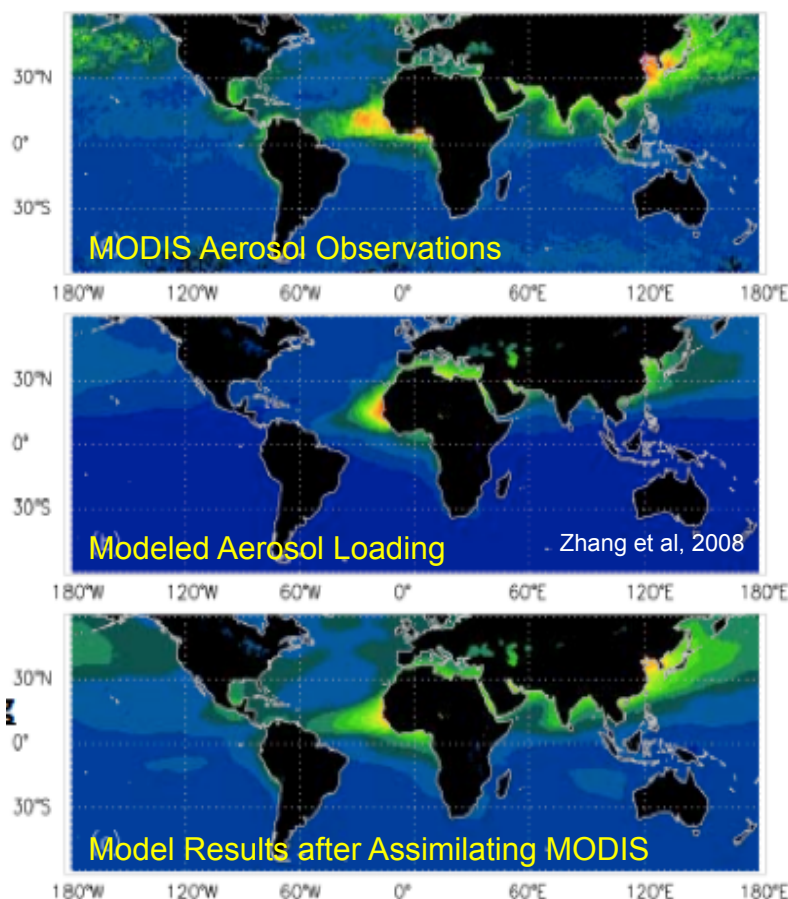
AIR QUALITY MONITORING





The Key Aerosol Problem: Why Lidar?

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Models are used to determine climate forcing and predict future climate change

Observations provide constraints needed to model aerosol properties and behavior

Even with those constraints, modeling aerosol distribution and loading is difficult

- Aerosol climate impacts are proportional to loading!

Model aerosol loading improves significantly after assimilating coincident observations, but only for 2D total loading (as shown)

Despite agreeing on total loading, current models diverge significantly on vertical distribution and aerosol type (ie pollution vs dust)

As a result, it is difficult to attribute aerosol loading to human vs nature (ie pollution vs dust)

- Determining human induced portion of aerosol climate impact is the primary goal!

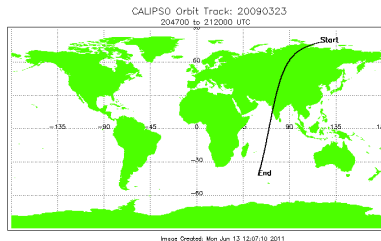
Aerosol climate forcing is dependent on vertical location: are aerosol below, mixed with, or above clouds?

- Aerosol-Cloud interactions comprise the largest uncertainty in climate forcing

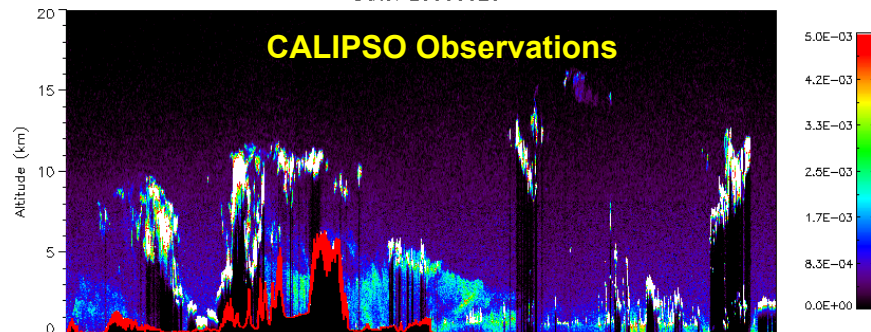


The Key Aerosol Problem: Why Lidar?

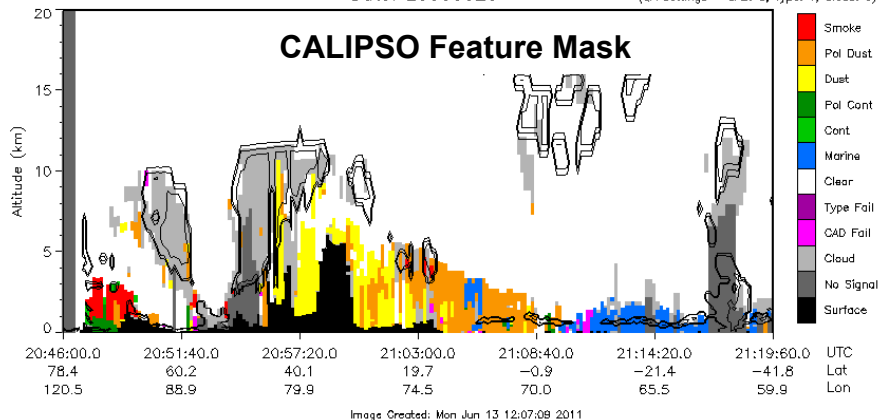
29



CALIPSO Attenuated Backscatter (V3.01): Signals
Date: 20090323



CALIPSO Vertical Feature Mask (V3.01): Aerosols
Date: 20090323
(QA Settings - QAD: 3, Type: 1, Cloud: 0)

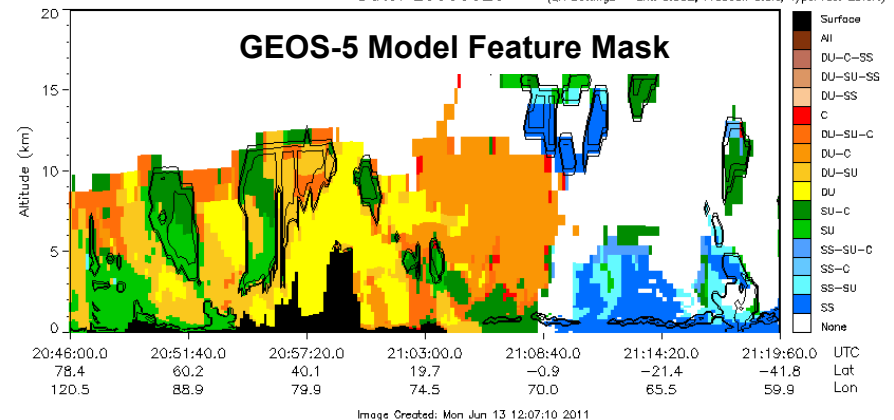


Lidar provides:

- (1) information on the vertical profile of aerosol type, and properties (ie loading)
 - similar information on clouds
- (2) heights of aerosols and clouds, and improves our understanding of how and when aerosol-cloud interactions occur

CATS will provide data to constrain modeled aerosol and cloud properties, and improve model distributions and climate forcing through assimilation

GEOS-5 Aerosols: Vertical Feature Mask
Date: 20090323
(QA Settings - Ext: 0.002, FracCol: 0.0%, TypeFrac: 25.0%)



Marine Aerosol

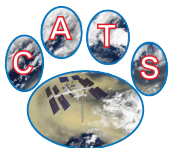
Pollution

Dust

Pollution-Dust

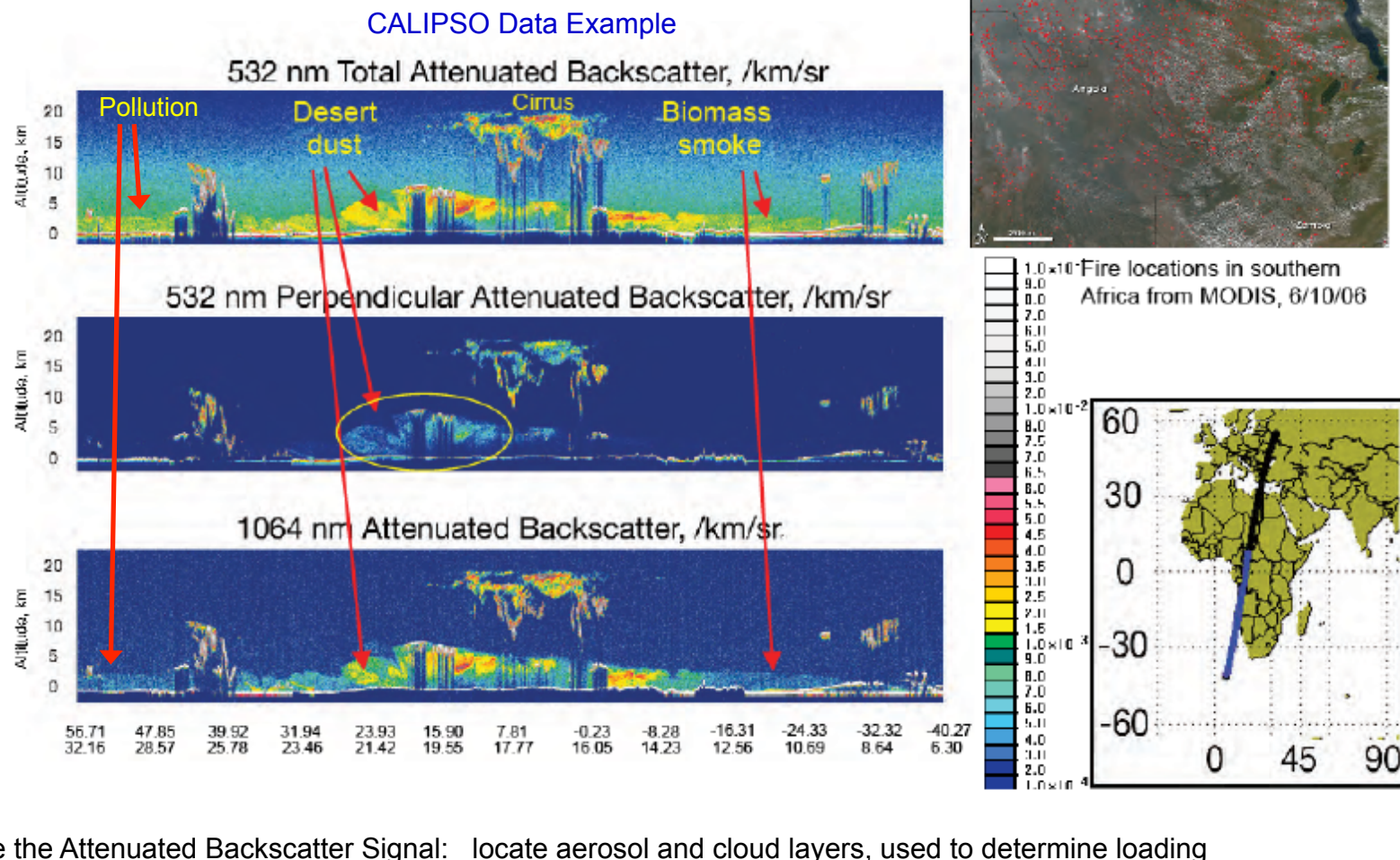
Smoke

Welton, et al (2011)



CATS Instrument Requirements

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Measure the Attenuated Backscatter Signal: locate aerosol and cloud layers, used to determine loading

Minimum of two wavelengths: provides information on particle size (pollution or smoke vs dust)

Minimum of depolarization at one wavelength: provides information on particle shape (dust vs marine)

Add 355 nm Attenuated Backscatter Channel: improves size estimate (1064 is difficult to calibrate and aerosol more sensitive to 355)

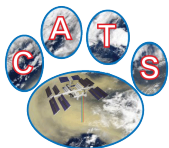
Add depolarization at 355 nm: recent studies indicate better typing for pollution & smoke (pollution, smoke, OR dust)



CATS Science Trace Matrix

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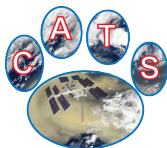
Mission Objectives	Geophysical Parameters	Measurement Requirements	Approach	Ancillary Data
(A) Continuity of CALIPSO Climate Observations (1) Improve observationally-based estimates of direct and indirect aerosol radiative forcing (2) Improve parameterizations of cloud-climate feedbacks (3) Improve the representation of aerosols and clouds in climate models	detection of aerosol and cloud layers from the surface to the stratosphere Attenuated Backscatter, aerosol and cloud backscatter and extinction depolarization ratio Aerosol and Cloud Type (feature mask)	Minimum Dual Wavelength Elastic Backscatter Lidar (532 and 1064 nm) Depolarization Ratio at 532 nm Measured Attenuated Backscatter Resolutions: < 100 m vertical, < 400 m along track (high res for cloud detection/clearing) Retrieved Backscatter: $1\text{E-}4$ (km sr) ⁻¹ at 100 m vertical, 20 km along track. 30% error.	Acquire data set similar to CPL and CALIPSO Develop retrieval algorithms based on ICESat and CPL experience In addition to above, apply CALIPSO algorithms to assess data continuity between missions Utilize model AOD from passive assimilation techniques to provide retrieval constraints, and improved aerosol lidar products	Meteorology (molecular calculations and science/analysis) Position/Pointing, and DEM Column Aerosol Optical Depth 532 nm (Observational or Assimilation Model) Scene Imagery (context)
(B) Provide Observational Data to Improve Operational Modeling Programs (1) Improve the three dimensional transport of aerosols in transport and air quality (AQ) forecast models (2) provide observational constraints to separate near surface aerosol concentrations from those in the free troposphere for AQ applications (3) Improve the parameterization of planetary boundary layer height in numerical weather prediction models	Above parameters, plus: Planetary Boundary Layer Height (feature mask)	Above requirements, plus: NRT capability: minimum ≤ 3 hours, max 1 day Observations across the diurnal cycle	Use lidar feature mask and retrieved aerosol properties to assess initial model performance Provide vertical profile products and PBL heights for model assimilation Provide a PBL AOD product from extinction profile and PBL height Utilize unique ISS orbit to improve studies of longitudinal aerosol transport and diurnal evolution of aerosol and PBL	
(C) ACE Lidar Pathfinder (1) demonstrate HSRL retrieval of extinction at 532 nm in space (2) provide observational data for ACE mission development	Direct Retrieval of Extinction and Backscatter at 532 nm Lidar Ratio at 532 nm	HSRL capability at 532 nm (notch filter or interferometric technique) Retrieved Extinction Resolutions: ≤ 1 km vertical, ≤ 50 km along track	Determine optimum resolution vs extinction limit, and feasibility of retrievals for broken cloud scenes Use HSRL extinction and lidar ratio profile products to provide improved aerosol typing for Mission Objectives B1 and B2	



CATS Science Trace Matrix

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Mission Objectives	
(A) Continuity of CALIPSO Climate Observations (1) Improve observationally-based estimates of direct and indirect aerosol radiative forcing (2) Improve parameterizations of cloud-climate feedbacks (3) Improve the representation of aerosols and clouds in climate models	(A) Continuity of CALIPSO Climate Observations Provide aerosol and cloud data to: <ul style="list-style-type: none">• Improve our understanding of their properties (constraints)• Perform observationally based assessments of climate change (no model)• Improve model based estimates of climate forcing and predictions of future climate change Instrument requirements as shown prior (layer detection, layer typing, layer properties - loading) Downlink (Level 0) Resolutions <ul style="list-style-type: none">< 100 m vertical< 400 m along track(Driven by need to separate aerosol and cloud) Detect backscatter down to $1\text{E-}4 \text{ (km sr)}^{-1}$ (Driven by aerosol & thin cloud loading) No Near Real Time Requirement



CATS Science Trace Matrix

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Mission Objectives

(B) Provide Observational Data to Improve Operational Modeling Programs

(1) improve the three dimensional transport of aerosols in transport and air quality (AQ) forecast models

(2) provide observational constraints to separate near surface aerosol concentrations from those in the free troposphere for AQ applications

(3) improve the parameterization of planetary boundary layer height in numerical weather prediction models

(B) Provide Observational Data to Improve Operational Modeling Programs

Provide aerosol and cloud data to:

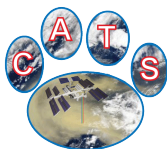
- Improve model performance through assimilation
- Air Quality – how much loading near surface vs aloft?
Where did it come from? (local vs transport)
- Strategic & Hazard Warning – Aerosol Forecasting ie,
What? Where? When?

Instrument requirements as shown prior
(same products + Planetary Boundary Layer Height)

Resolutions and Detection Limits the same

Near Real Time Product Delivery to Operational Center
≤ 3 hours to 1 day max lag time (shorter better)
subset of products ok, do not need full delivery

Observations across the diurnal cycle



CATS Science Trace Matrix

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Mission Objectives

(C) ACE Lidar Pathfinder

Demonstrate HSRL retrieval of aerosol extinction from space and provide observational data for mission development (performance)

No Instrument Requirements

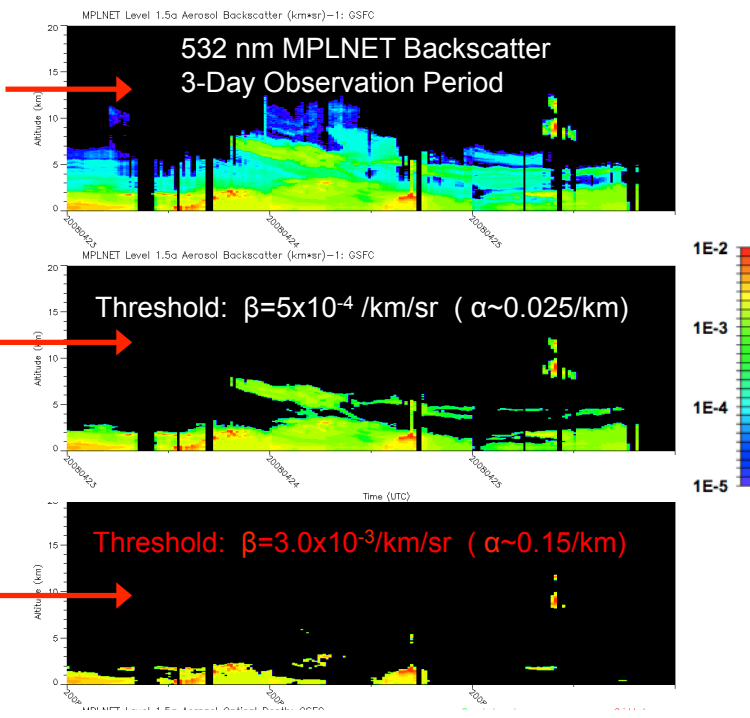
ACE Science Working Group:
Vertical resolution requirements:
≤ 500 m in boundary layer
≤ 1 km in free troposphere

Ground Based Retrieval of Aerosol Backscatter: down to $1\text{E-}5 \text{ (km sr)}^{-1}$

ACE Lidar Working Group
Estimates of HSRL Retrievals:

Threshold at 1 km vertical
(for 50 km along track average)

Threshold at 500 m vertical
(for 10 km along track average)
Correlation scales are short near the surface, which limits along track averaging



(C) ACE Lidar Pathfinder

(1) demonstrate HSRL retrieval of extinction at 532 nm in space

(2) provide observational data for ACE mission development



Performance Simulation: Detection Limits

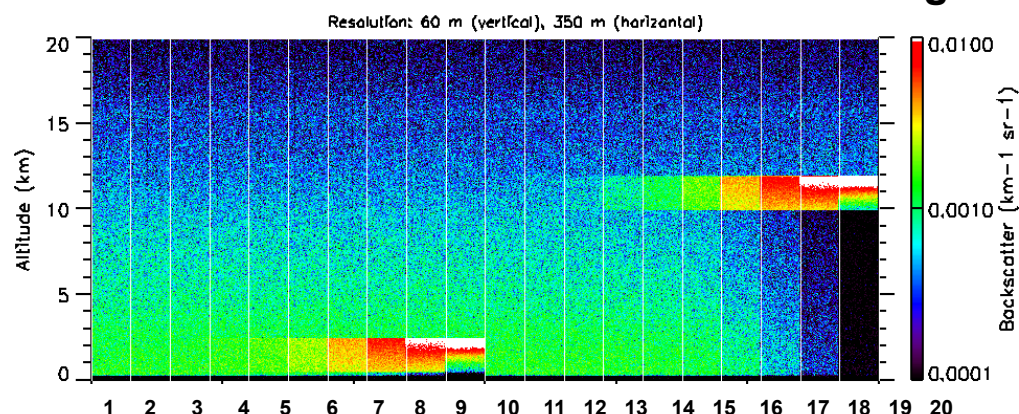
35

Simulation prepared similar to CALIPSO approach.

Attenuated Backscatter signal constructed at expected Level 0 downlinked resolution (350 m along track, 60 m vertical)

- Aerosol Layer simulated in first 10 segments (lidar ratio = 30 sr, weak sea salt layer)
- Cirrus Layer in segments 11-20 (lidar ratio = 25 sr, typical for thin cirrus)

CATS Simulated Attenuated Backscatter: Night



Segment	Distance	Height	Backscatter (km ⁻¹ sr ⁻¹)	Optical Depth
1	0-80 km	0.5-2.5 km	3.00E-05	0.002
2	80-160 km	0.5-2.5 km	7.00E-05	0.004
3	160-240 km	0.5-2.5 km	1.30E-04	0.008
4	240-320 km	0.5-2.5 km	3.30E-04	0.020
5	320-400 km	0.5-2.5 km	6.70E-04	0.040
6	400-480 km	0.5-2.5 km	1.33E-03	0.080
7	480-560 km	0.5-2.5 km	3.33E-03	0.200
8	560-640 km	0.5-2.5 km	6.67E-03	0.400
9	640-720 km	0.5-2.5 km	1.33E-02	0.800
10	720-800 km	0.5-2.5 km	3.33E-02	2.000
11	800-880 km	10-12 km	4.00E-05	0.002
12	880-960 km	10-12 km	8.00E-05	0.004
13	960-1040 km	10-12 km	1.60E-04	0.008
14	1040-1120 km	10-12 km	4.00E-04	0.020
15	1120-1200 km	10-12 km	8.00E-04	0.040
16	1200-1280 km	10-12 km	1.60E-03	0.080
17	1280-1360 km	10-12 km	4.00E-03	0.200
18	1360-1440 km	10-12 km	8.00E-03	0.400
19	1440-1520 km	10-12 km	1.60E-02	0.800
20	1520-1600 km	10-12 km	4.00E-02	2.000

Detection algorithm applied to each layer and segment based on Yorks et al. (2011) and Palm et al. (2002)

Detection improves as layer concentration/backscatter increases. Find optimum averaging to detect layer.

* These results are preliminary, and operational algorithm will likely do better (as occurred with CALIPSO operational algorithm vs theoretical limits)

Simulation	Layer	Backscatter Detection Thresholds (km ⁻¹ sr ⁻¹)				
		350 m	1 km	5 km	20 km	80 km
Night	0.5 – 2.5 km	1.33 E-3	6.70 E-4	3.33 E-4	3.33 E-4	1.30 E-4
	10 – 12 km	1.00 E-3	4.00 E-4	4.00 E-4	4.00 E-4	1.60 E-4
Day	0.5 – 2.5 km	CATS Daytime Simulation is underway				
	10 – 12 km					



Conclusion

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A Science Simulation is under development:

Generate more realistic aerosol and cloud profiles along the ISS orbit track using GEOS-5 model results.

Detection and retrieval algorithms can be tested against “truth” from the model input and refined for optimum performance.

Results will be used to develop approach to operational modeling goals.

Aerosol and Cloud Lidars in Space:

CALIPSO: 2006 – current

First Laser: May 2006 – March 2009

Second Laser: March 2009 – current (* **could be 2015**)

~ 2.5 years operational life each demonstrated

CATS: June 2013 launch

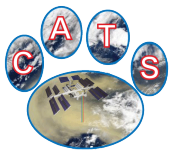
6 month requirement, 3 year goal

Hopefully include crossover with CALIPSO & bridge to Earthcare

ESA Earthcare: ~**2015** launch likely after delays with lidar

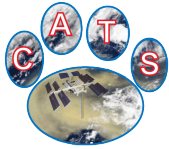
ACE: 2020's

CATS will fill what would have been a critical gap in the climate data record from lidar, improve operational aerosol forecasting, provide a bridge between CALIPSO and Earthcare, and contribute to ongoing ACE mission development.



CATS Optical

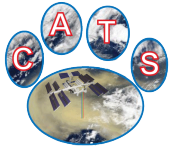
Stan Scott
GSFC Code 694



Team

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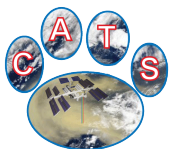
- Stan Scott/ 694
 - Optics Lead
 - Optical design, analysis, I&T oversight
- Andrew Kupchock/ SSAI/ 613.1
 - Optical alignment
 - Assistant to Lead
- Robert Switzer/ MUNIZ/ 560
 - Fiber development
- Fibertek
 - Laser development
- Axsys
 - Telescope



Driving Requirements

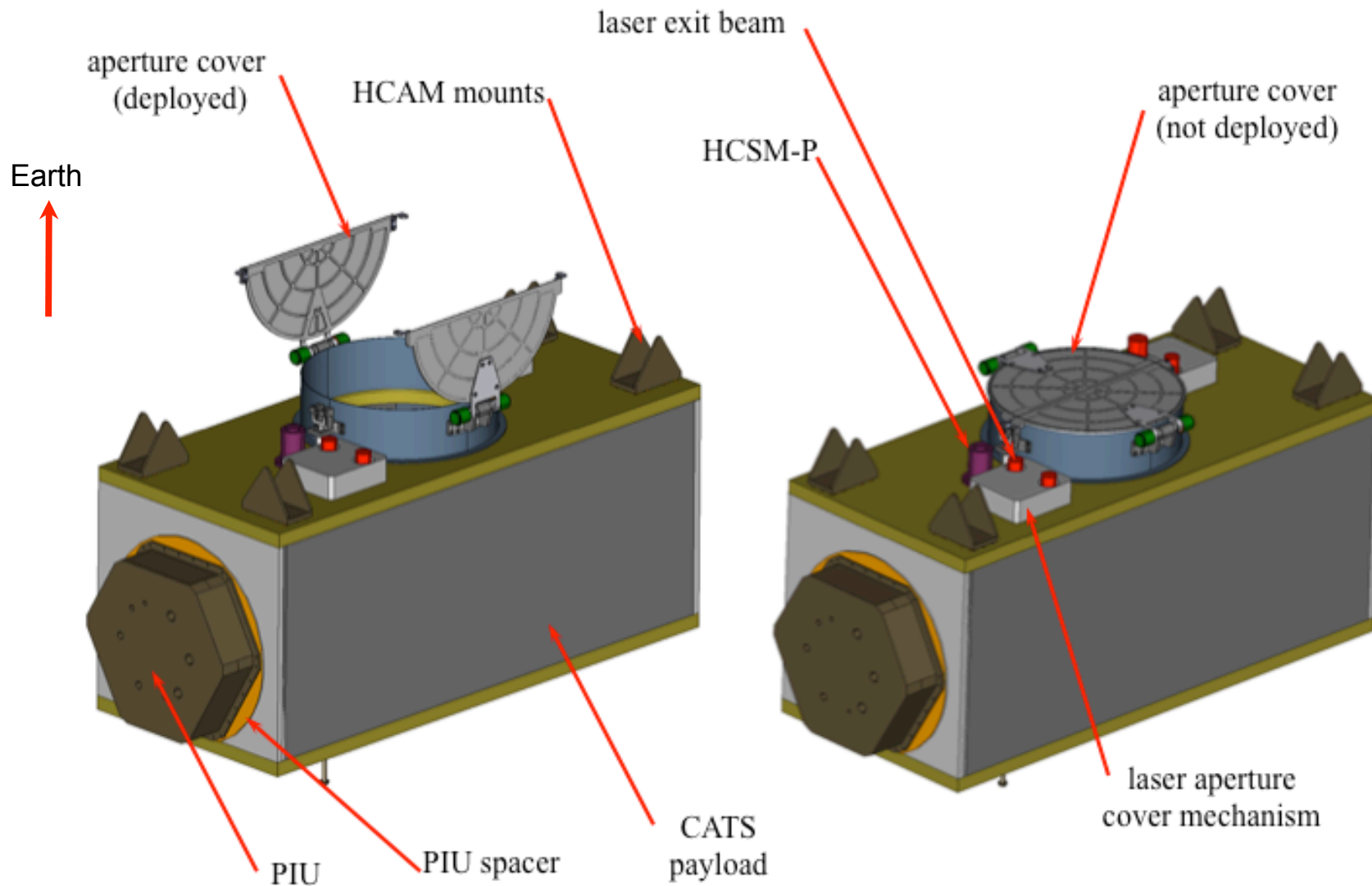
39

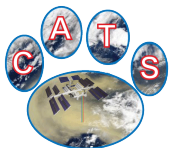
- Provide a transceiver with similar performance to the ER2-CPL at the ISS orbit.
- Provide a transceiver that is capable of making the HSRL measurement at the ISS orbit.
- Provide de-polarization channels on every channel with the exception of the HSRL channel.
- Use COTS where ever possible to save costs.
- Be able to have the instrument ready for environmental testing at the start of 2013.



Payload Exterior Features

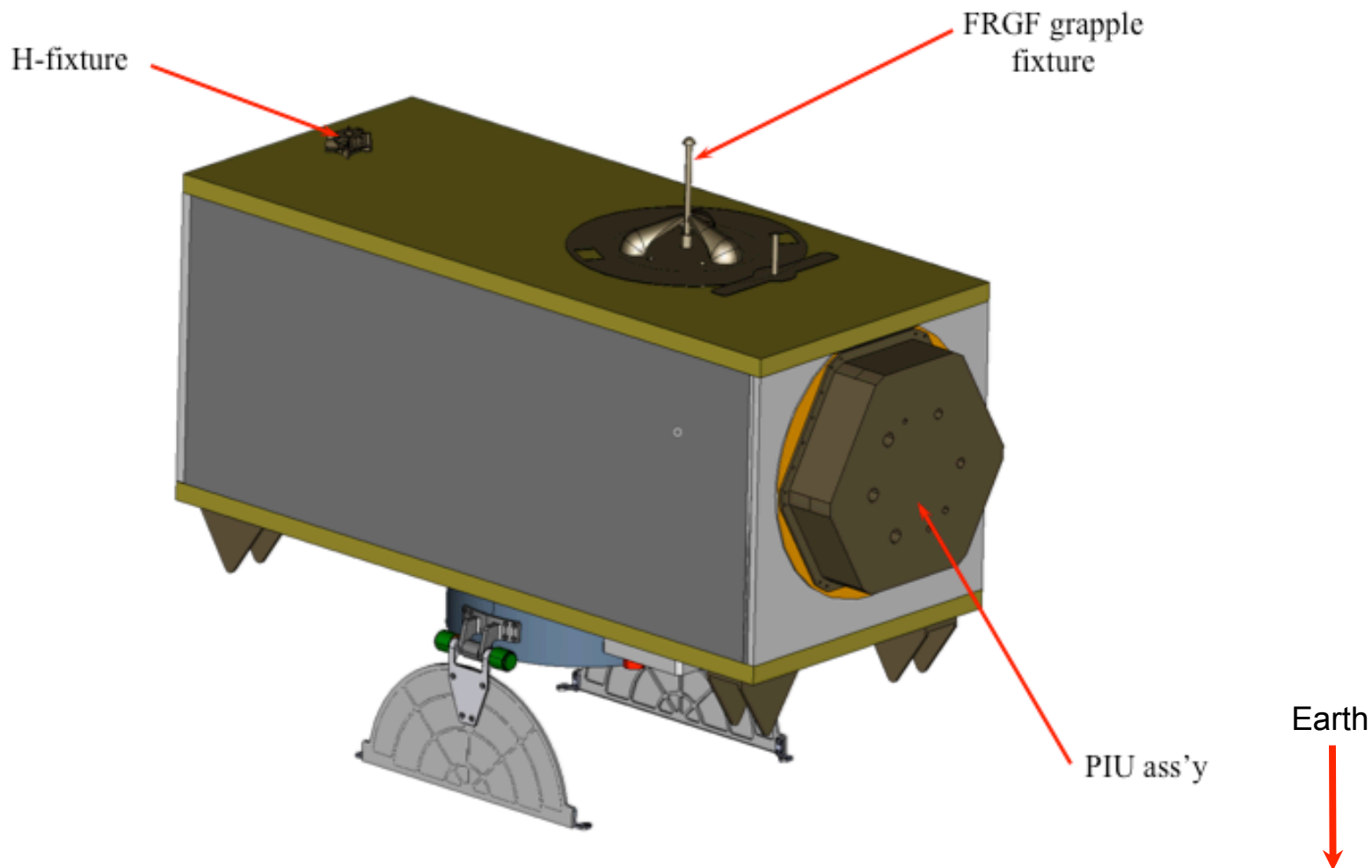
40





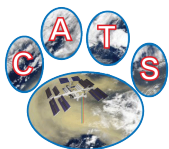
Payload-to-ISS Mechanical Interfaces

41



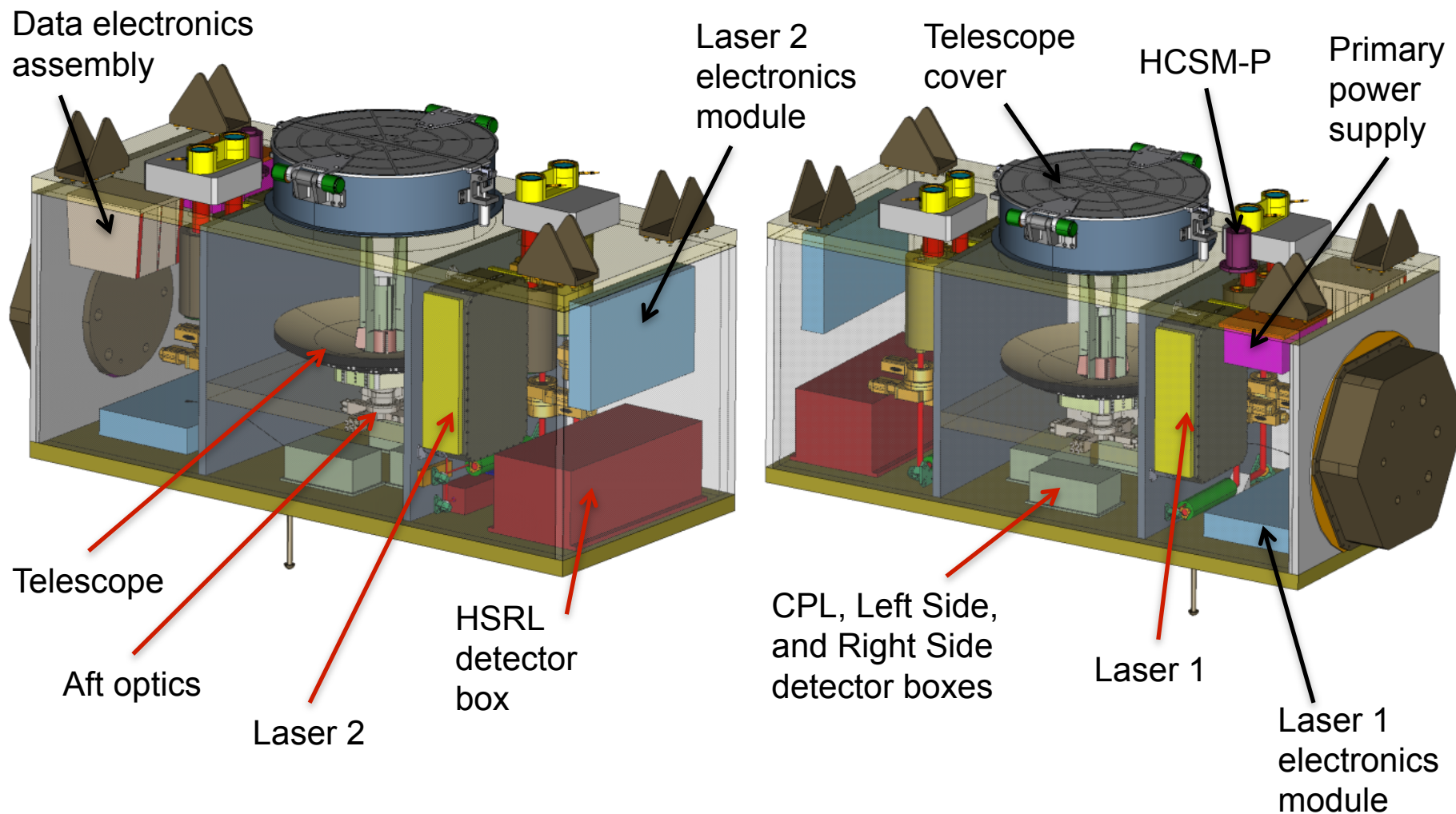
Standard JEM-EF payload volume: 1.855 x 0.800 x 1.299 m.

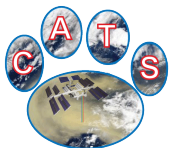
Total payload height is 51 inches including the 12 inches of protrusion required for the grapple fixture, per NASDA-ESPC-2857(rev C, part 2, vol 2), Figure 3.3.1.1.1-2.



CATS Optical Assemblies

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Instrument Subassembly Definitions

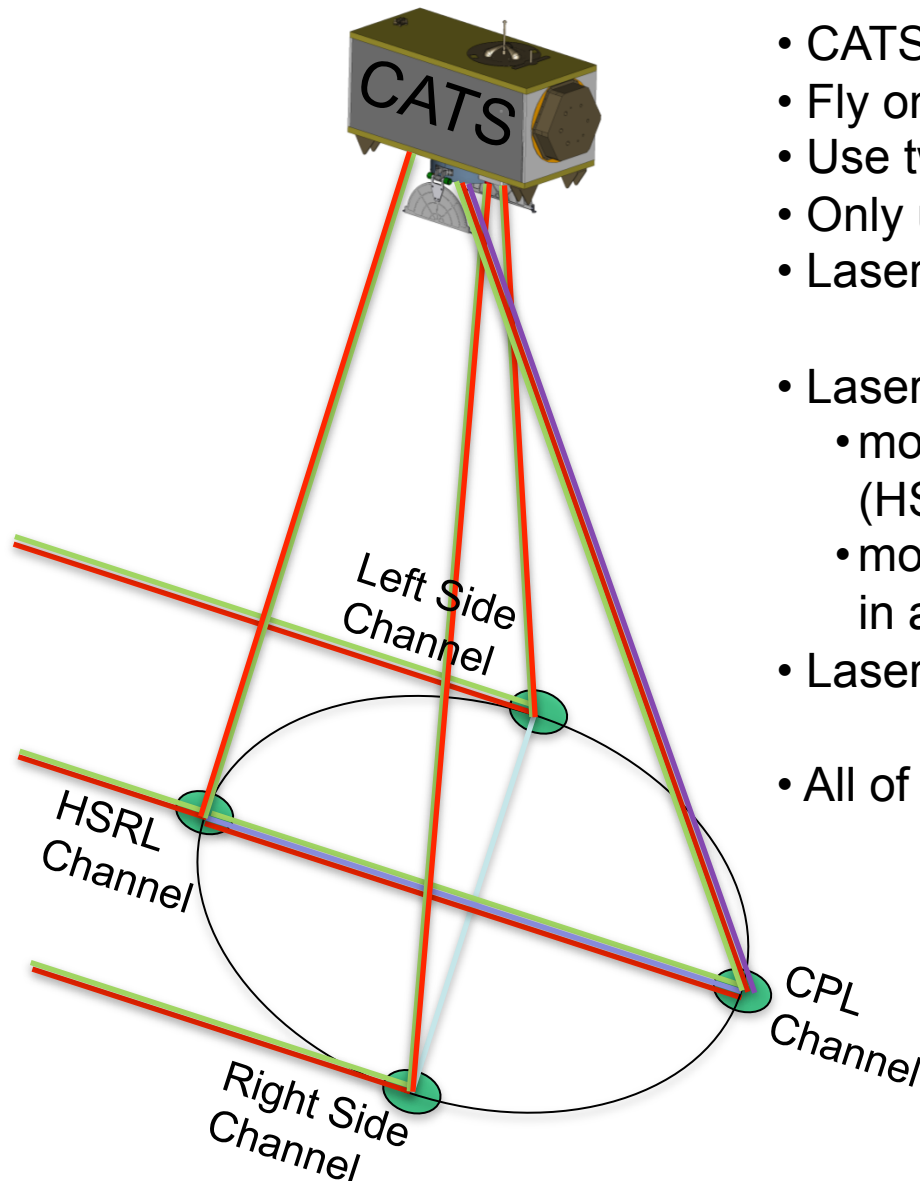
43

name	function	hazards inherent to subassembly
Laser #1	provides simultaneous 1064/532 nm output	non-ionizing radiation; sealed volume; high voltage internal to box
Laser #2	provides simultaneous 1064/532/355 nm output	non-ionizing radiation; sealed volume; high voltage internal to box
Laser2a CPL receiver box	works with laser #2 to provide 3-wavelength detection	sealed volume; high voltage internal to detectors
Laser2b HSRL receiver box	works with laser #2 to provide 2-wavelength detection using HSRL receiver	sealed volume; high voltage internal to detectors and etalon
Laser1 left receiver box (LSFOV)	works with laser #1 to provide 2-wavelength detection, looking 0.5 degrees to left side	sealed volume; high voltage internal to detectors
Laser1 right receiver box (RSFOV)	works with laser #1 to provide 2-wavelength detection, looking 0.5 degrees to right side	sealed volume; high voltage internal to detectors
Data system	provides electrical distribution, system control, data collection, and interface to ISS	electrical
Telescope assembly	receives backscattered light, passes to receiver boxes	fracture
Primary power supply	Converts 110 VDC to 28 VDC for laser power & down-converting	electrical

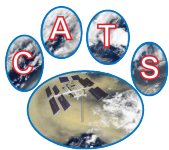


Optical Measurement Concept

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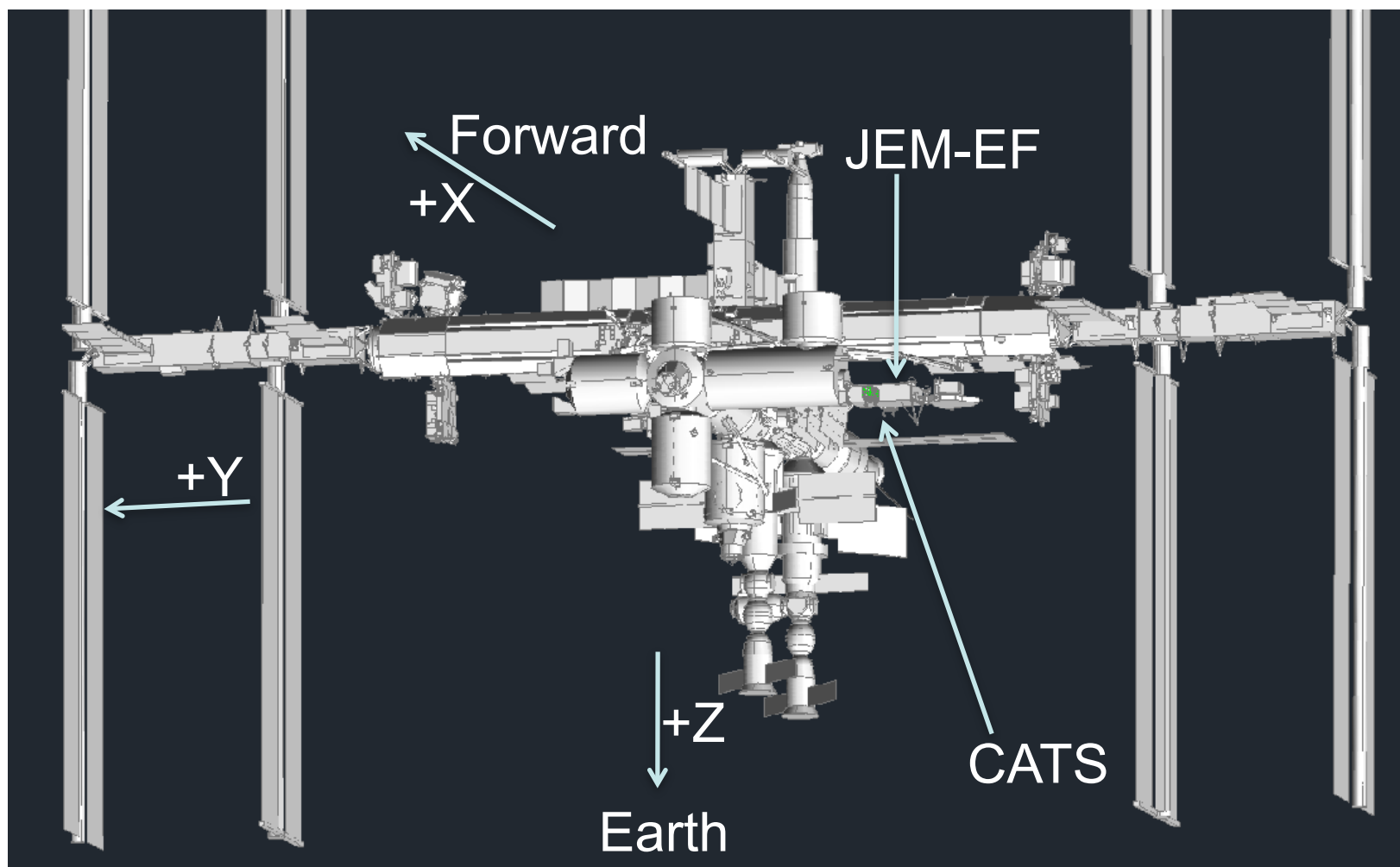


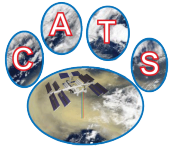
- CATS is a lidar, not an altimeter
- Fly on ISS at ~ 420 km
- Use two 532 nm/1064 nm lasers
- Only use one at a time
- Laser 1 is split and aimed at $+0.5$ and -0.5 degrees left and right of payload nadir
- Laser 2 has two modes
 - mode 1 acts as an 532 nm HSRL system (HSRL) and 1064 nm backscatter.
 - mode 2 has a THG to generate 355nm light in addition to the 532 nm and 1064 nm (CPL)
- Laser 2 can also be switched to either of the laser 1 receiver channels
- All of the receiver channels have the ability to measure depolarization (except HSRL)



Where Are We?

45

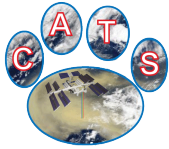




CATS Transmitter Baseline

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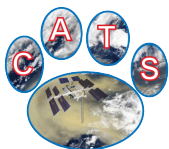
- Fibertek will deliver two Nd:YVO₄ lasers.
- The two lasers will increase lifetime and allow the desired technology demonstration options
- The lasers baseline will be 4 to 5 kHz and >2 mJ per pulse per wavelength.
- Laser 1 will be only 532 nm/1064 nm operation and be used for the left and right side multiple IFOV channels.
- Laser 2 will have the ability to add the 355 nm in orbit.
- When laser 2 is operating at all three wavelengths, it will be in the CPL channel mode.
- When laser 2 is operating with only two wavelength, it will be in the HSRL channel mode.



Laser 1 Performance Parameters

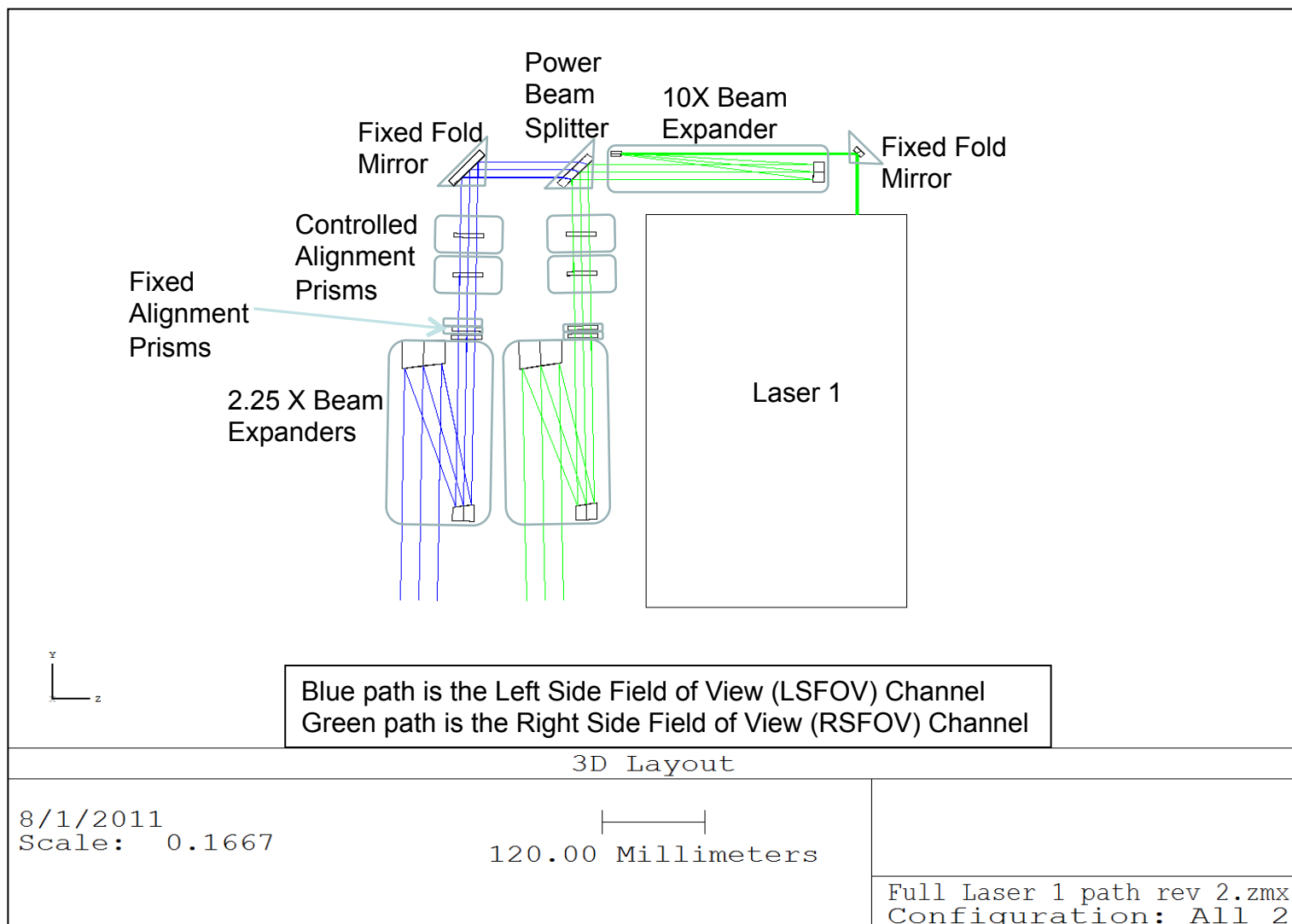
47

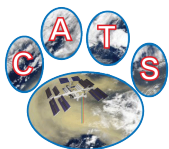
- Laser Medium: Nd:YVO₄
- Output Energy: > 2.5 mJ @1064 nm,
> 2.5 mJ @532 nm
- Output divergence (1/e²): 1.5 mrad +/- 0.2 @1064 nm,
0.745 mrad +/- 0.105 @532 nm
- Output beam size (1/e²): 1.27 mm @532 nm and 1064 nm
- Vacuum Wavelength: 1064.521 nm +/- 0.003 nm,
532.261 nm +/- 0.002 nm
- M²: < 1.6 @1064 nm,
1.3 +/- 0.1 @532 nm
- Polarization: > 100:1 @ 532 nm and 1064 nm
- Rep Rate: 5 kHz
- Pulse Width: 6 nsec +/- 1 nsec
- Line Width: 150 +/- 50 pm @1064 nm,
<150 pm @532 nm



Laser 1 Transmit Path

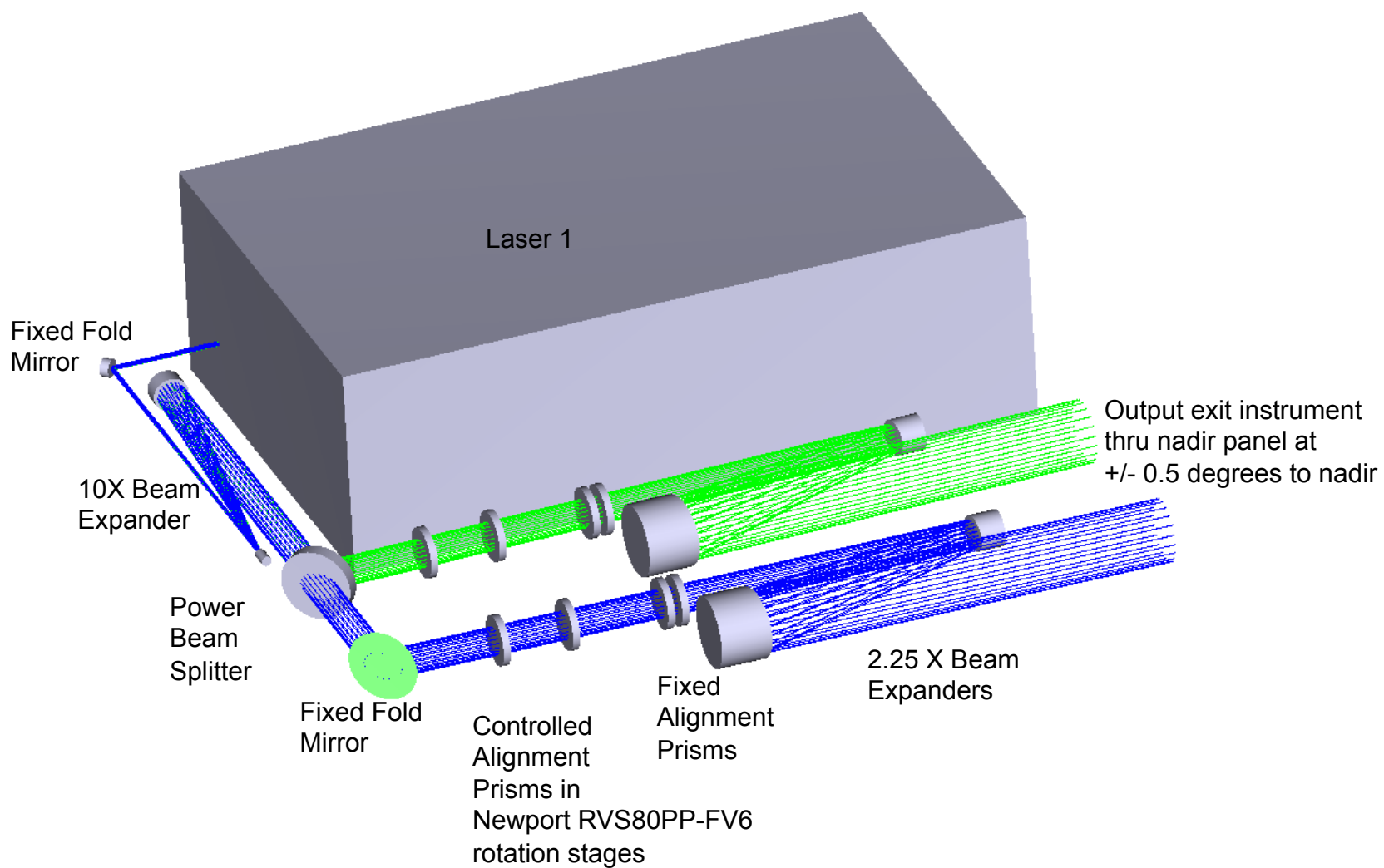
48





Laser 1 Layout

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10X Beam Expander

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Design

Expansion Ratio: 10X

Input beam size ($1/e^2$): 1.27 mm

M1 efl: -25 mm

M1 diameter: 7.0 mm

M1 offset (OAD1): -1.0 mm

M2 efl: 250 mm

M2 diameter: 25.0 mm

M2 offset (OAD1): 12.5 mm

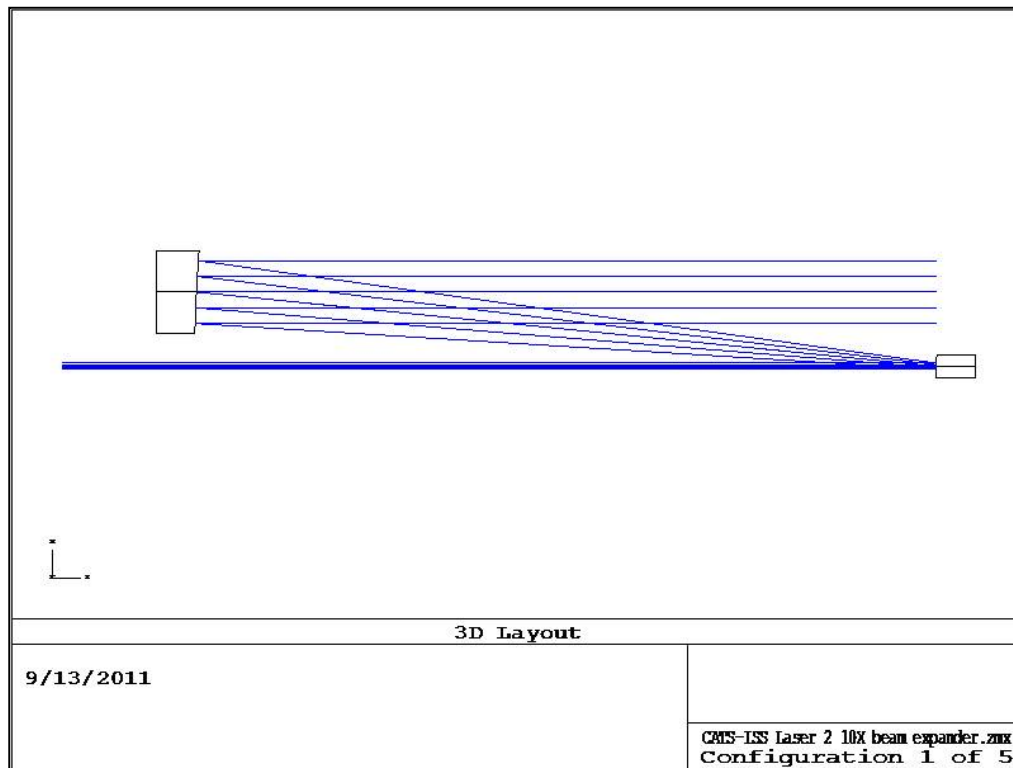
Spacing: 225 mm

Output beam size ($1/e^2$): 12.7 mm

Output divergence ($1/e^2$):

75 μ rad \pm 11 μ rad @532nm

150 μ rad \pm 20 μ rad @1064nm



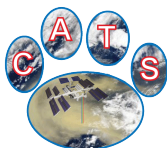
Sensitivities

Laser AOI: 0.100 mrad/mrad, pointing

BE Tilt: 0.900 mrad/mrad, pointing

M1-M2 de-center: 4.0 mrad/mm, pointing

M1-M2 de-focus: 0.43 mrad/mm, divergence (geo)



2.25X Beam Expander

51

Design

Expansion Ratio: 2.25X

Input beam size ($1/e^2$): 12.7 mm

M1 efl: -140 mm

M1 diameter: 25.0 mm

M1 offset (OAD1): 27.5 mm

M2 efl: 315 mm

M2 diameter: 50.0 mm

M2 offset (OAD1): 65.0 mm

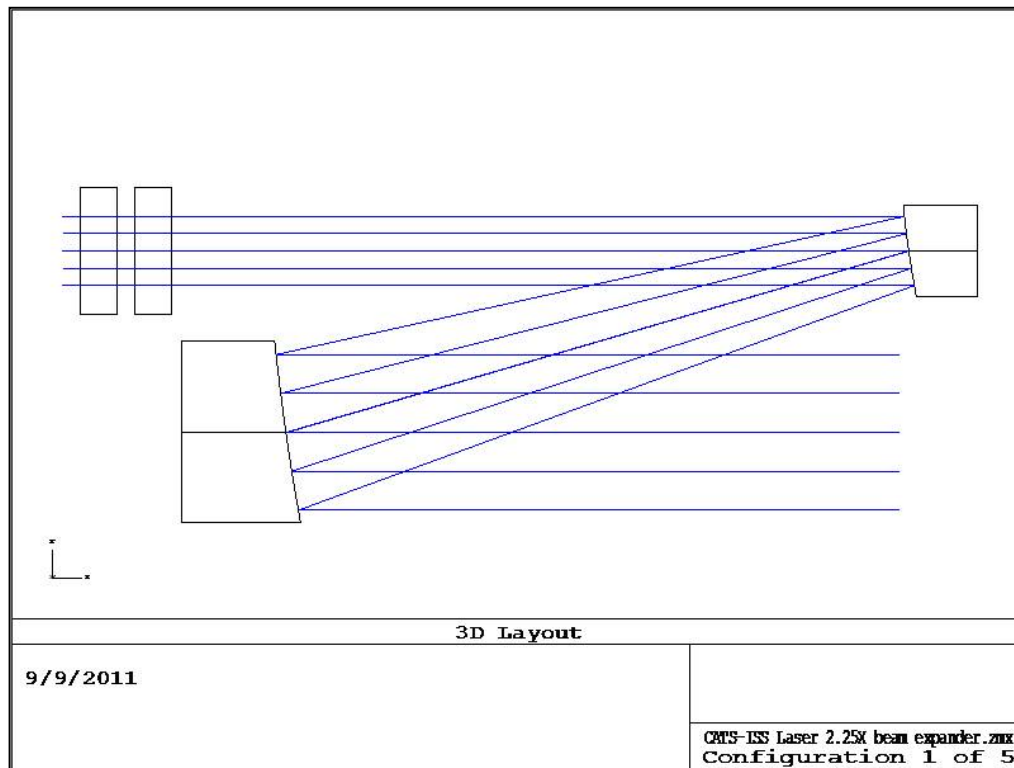
Spacing: 175 mm

Output beam size ($1/e^2$): 28.6 mm

Output divergence ($1/e^2$):

33 μ rad \pm 5 μ rad @532nm

67 μ rad \pm 9 μ rad @1064nm



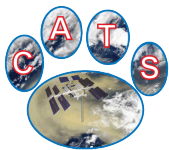
Sensitivities

Laser AOI: 0.444 mrad/mrad, pointing

BE Tilt: 0.556 mrad/mrad, pointing

M1-M2 de-center: 3.0 mrad/mm, pointing

M1-M2 de-focus: 1.00 mrad/mm, divergence (geo)



Laser 2 Performance Parameters

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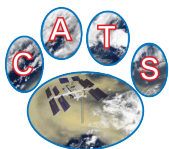
- Laser Medium: Nd:YVO₄
- Output Energy: ~ 3.0 mJ @1064 nm,
~ 3.0 mJ @532 nm
- Output divergence (1/e²): 1.5 mrad +/- 0.2 @1064 nm,
0.745 mrad +/- 0.105 @532 nm
- Output beam size (1/e²): 1.27 mm @532 nm and 1064 nm
- Vacuum Wavelength: 1064.521 nm +/- 0.003 nm,
532.261 nm +/- 0.002 nm
- M²: < 1.6 @1064 nm,
1.3 +/- 0.1 @532 nm
- Polarization: > 100:1 @ 532 nm and 1064 nm
- Rep Rate: 4 kHz
- Pulse Width: 6 nsec +/- 1 nsec
- Line Width: <0.5 pm @532 nm and 1064 nm



Laser 2 Performance Parameters (with THG)

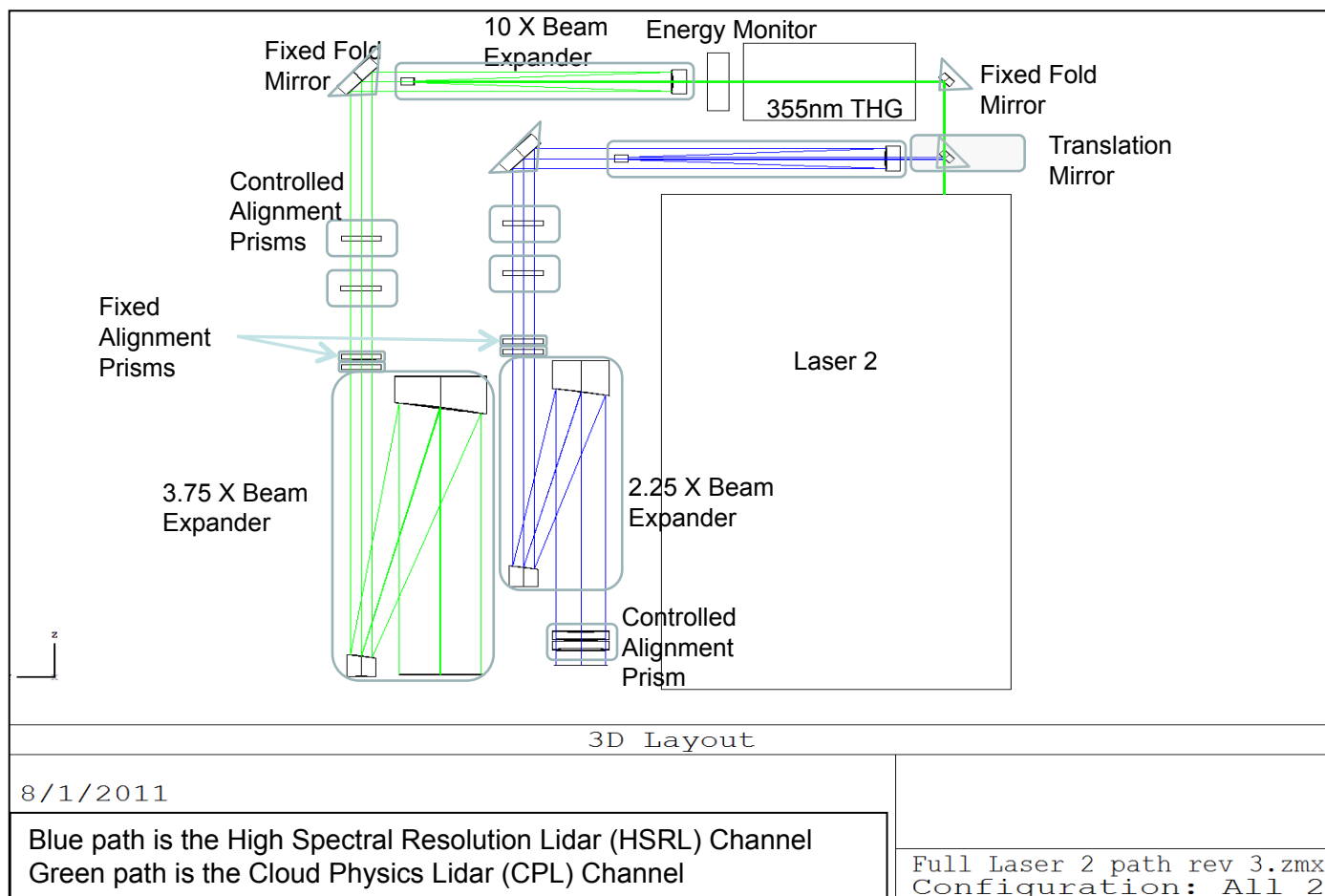
53

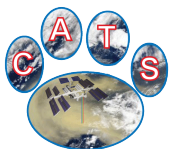
- Laser Medium: Nd:YVO₄
- Output Energy: >2.0 mJ @1064 nm,
<2.0 mJ @532 nm,
~2.0 mJ @355 nm
- Output divergence (1/e²): >2.1 mrad @1064 nm,
>1.05 mrad @532 nm,
>0.7 mrad @355 nm
- Output beam size (1/e²): 1.27 mm @355, 532 and 1064 nm
- Vacuum Wavelength: 1064.521 nm +/- 0.003 nm,
532.261 nm +/- 0.002 nm
355.840 nm +/- 0.001 nm
- M²: > 2 @ @355, 532 and 1064 nm
- Polarization: > 100:1 @355, 532 and 1064 nm
- Rep Rate: 4 kHz
- Pulse Width: 6 nsec +/- 1 nsec
- Line Width: <0.5pm @355, 532 and 1064 nm



Laser 2 Transmit Path

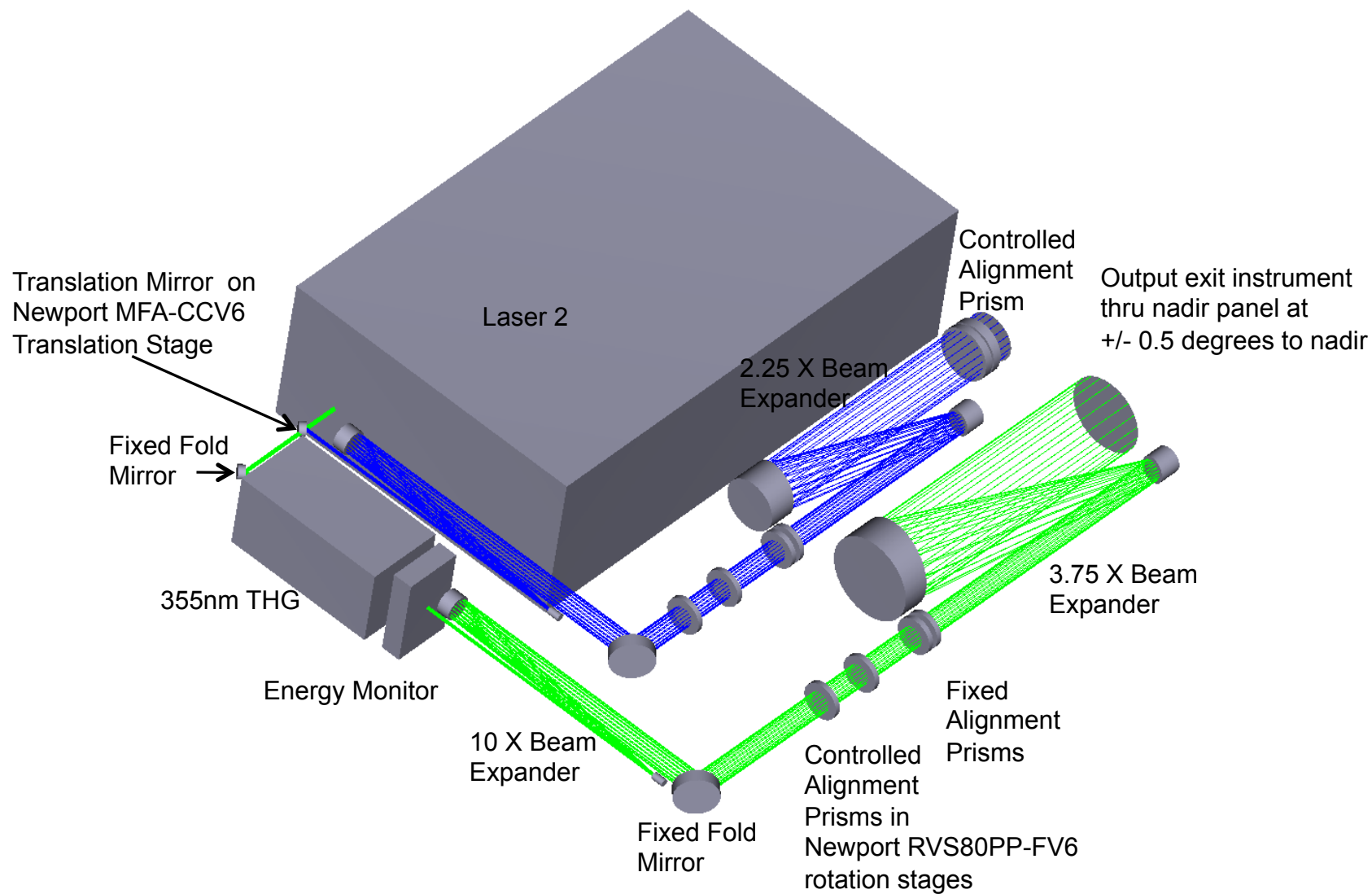
54

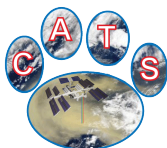




Laser 2 Layout

55





3.75X Beam Expander

56

Design

Expansion Ratio: 3.75X

Input beam size ($1/e^2$): 12.7 mm

M1 efl: -90.0 mm

M1 diameter: 25.0 mm

M1 offset (OAD1): 12.5 mm

M2 efl: 337.5 mm

M2 diameter: 80.0 mm

M2 offset (OAD1): 29.0 mm

Spacing: 247.5 mm

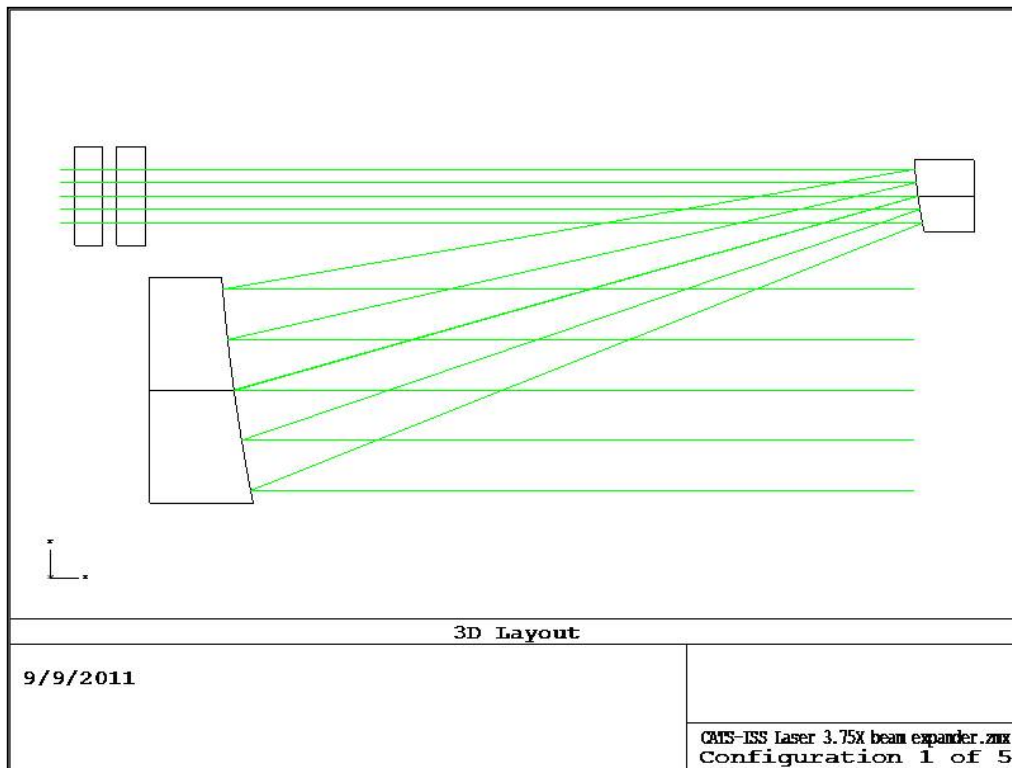
Output beam size ($1/e^2$): 47.6 mm

Output divergence ($1/e^2$):

23 μ rad \pm 4 μ rad @355nm

33 μ rad \pm 5 μ rad @532nm

67 μ rad \pm 11 μ rad @1064nm



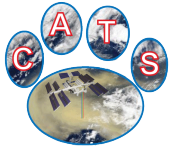
Sensitivities

Laser AOI: 0.267 mrad/mrad, pointing

BE Tilt: 0.733 mrad/mrad, pointing

M1-M2 de-center: 2.9 mrad/mm, pointing

M1-M2 de-focus: 1.06 mrad/mm, divergence (geo)



Laser Transmitters

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Developed by Fibertek.

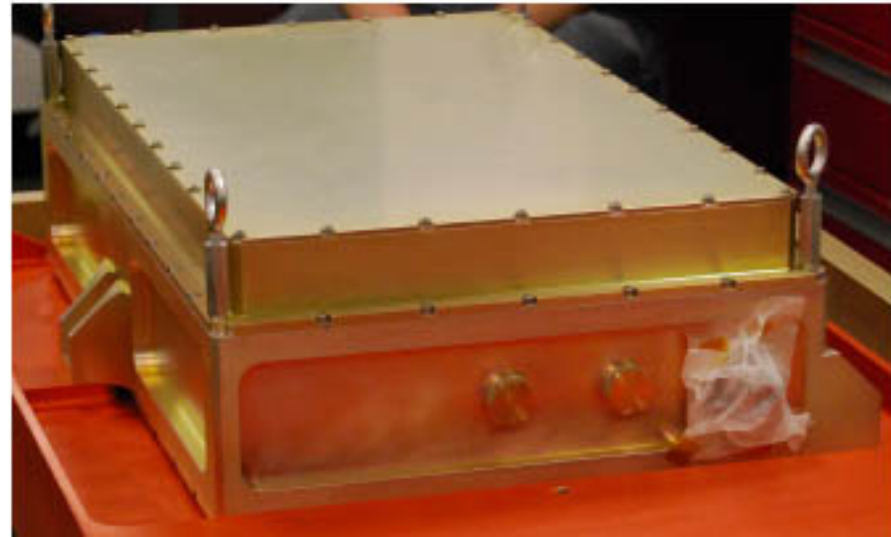
Fibertek has extensive experience
developing space-qualified
lasers.

Payload has two laser units.

Sealed boxes

- thermal control
- contamination control
- electrical (HV present internal)

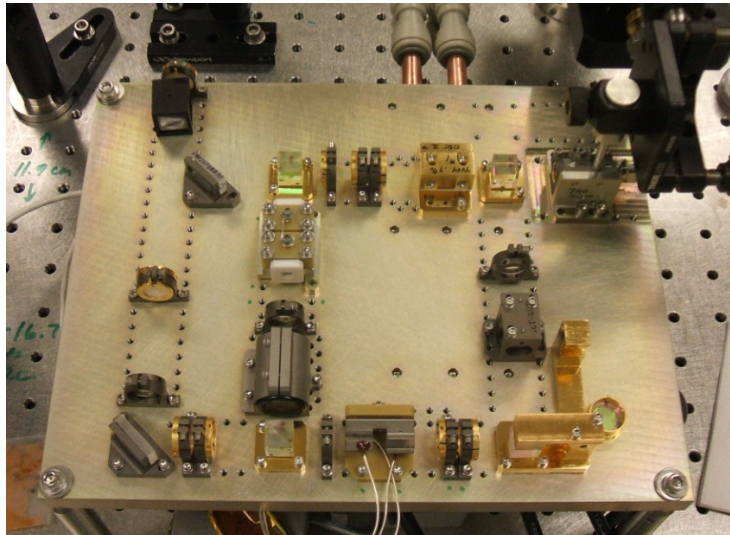
Each laser consists of two boxes:
one sealed box for the optical
head and one vented box for the
associated electronics.





Laser Transmitter Brassboard Performance

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Laser 2

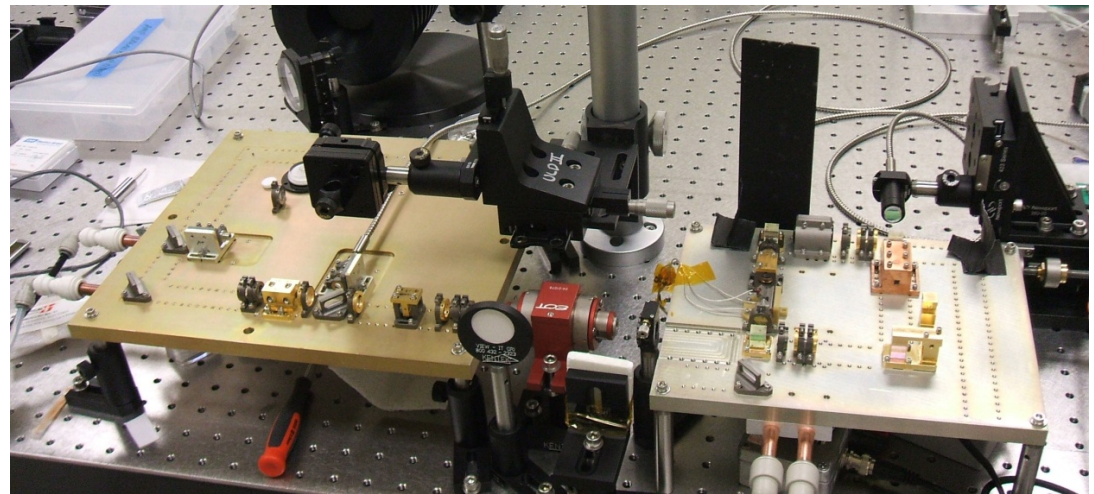
Single frequency brassboard oscillator

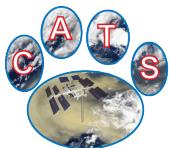
Basis for 3λ transmitter build

4 KHz, 1.5 mJ, $M^2 \sim 1.1$

Successfully injection seeded at 4 kHz

Laser 1
5 kHz brassboard amp demo
Dual amplifiers
Basis for 2λ transmitter build
5 KHz, >5.3 mJ/pulse

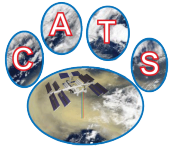




Alignment Risleys

59

	Full beam deviation	Color separation post BX at full beam deviation (532/ 1064)	Color separation post BX at full beam deviation (532/ 355)	Place used
0.050 FS wedge	357 μ rad	8.6 μ rad	n/a	Left Side, Right Side, and HSRL alignment
0.080 FS wedge	355 μ rad	8.2 μ rad	11.4 μ rad	CPL alignment
Achromatic wedge pair	8.00 mrad	0.1 μ rad	n/a	HSRL channel redirect



Newport Stages

60

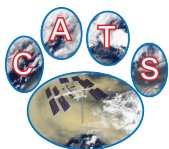
- We currently plan to use one (1) Newport MFA-CCV6 translation stage and nine (9) Newport RVS80PP-FV6 rotation stages
- The stages are vacuum rated.
- We have the translation stage that we plan to test now.
- We expect delivery of two of the rotation stages by mid October.
- We will vibration test the stages when we get them.



Newport MFA-CCV6 Translation Stage



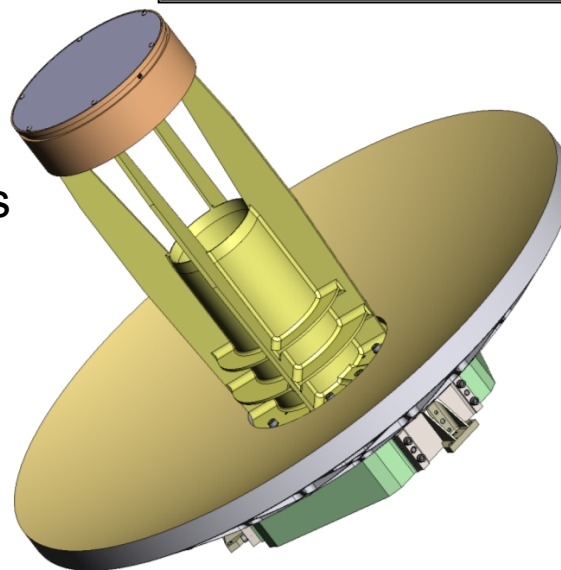
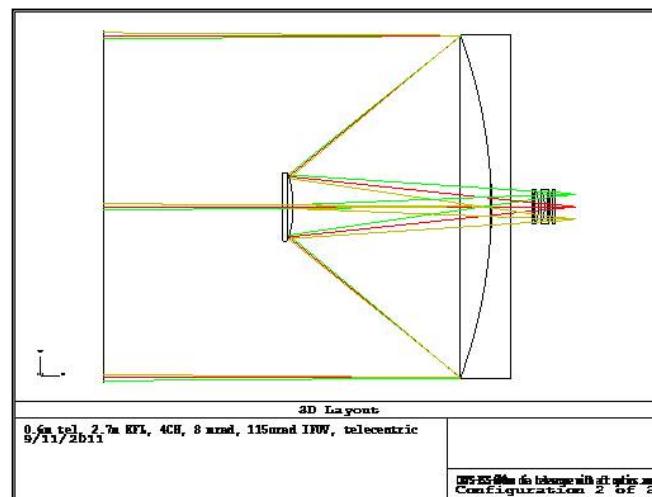
Newport RVS80PP-FV6 Rotation Stage



Telescope

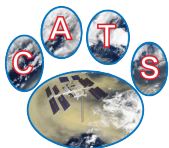
61

- Scaled version of the ATLAS 80 cm aperture telescope.
- Ritchie Chretien design
- Diameter: 0.60 m
- EFL: 2.85 m (telescope alone)
- Field of View: 16 mrad full angle
- IFOV: 115 μ rad
- EFL: 2.70 m with field correction optics
- Nearly telecentric



Current AXSYS
Model

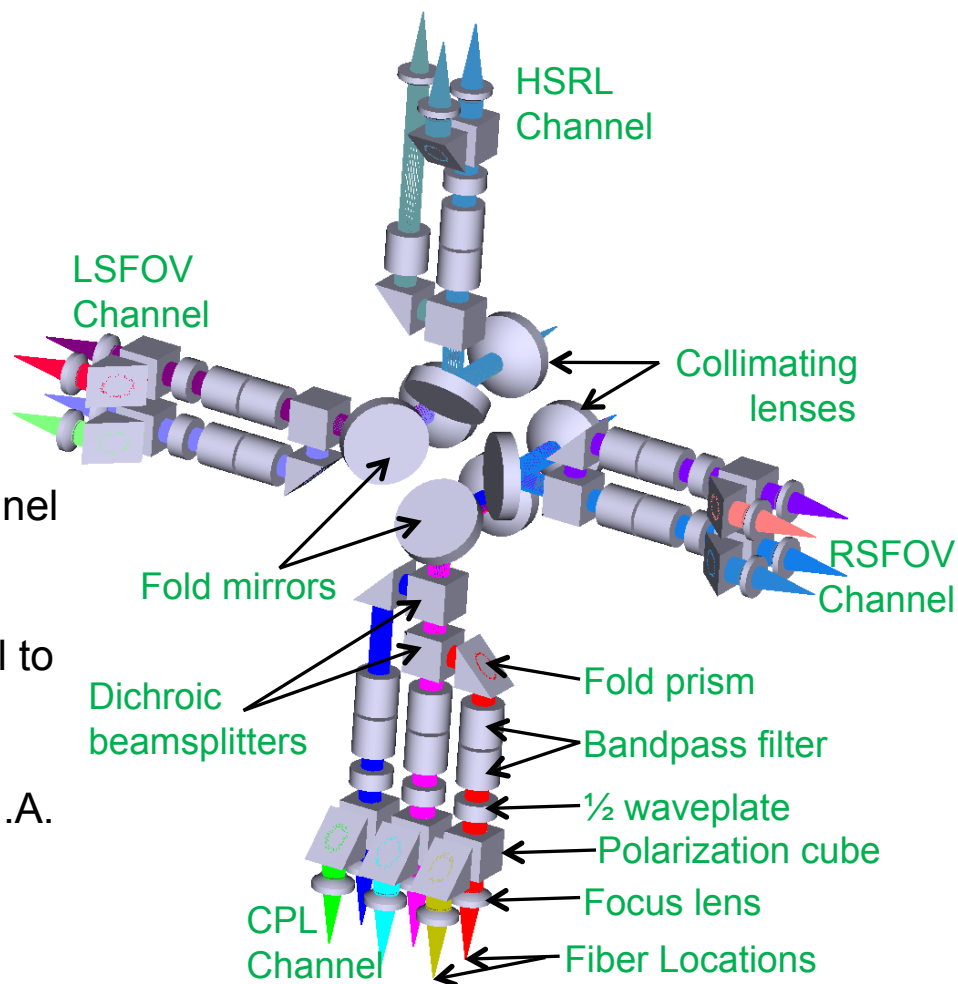
AXSYS Proprietary

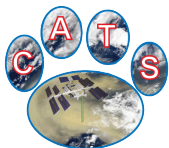


17 receiver channels total:

- 1 – 532 nm HSRL channel
- 2 – 355 nm depolarization channels
- 6 – 532 nm depolarization channels
- 8 – 1064 nm depolarization channels

- 30 mm efl asphere collimates telescope input
- Double 2-cavity bandpass filters on each channel
 - HSRL single bandpass filter (has etalon)
- $\frac{1}{2}$ -wave plates on each depolarization channel to align with laser output
- 20 mm efl aspheres focus into 200 μm , 0.22 N.A. fibers
 - (0.12 N.A. on HSRL channel)
- OTS lenses, mirrors, polarization cubes, right angle prisms and waveplates
- Custom filters and dichroic beamsplitter cubes





Detector Box Block Diagram

63

Left Side Detector Box

- 2 - 532 Power Splitters
- 4 - SPCM's for 532 nm detection
- 2 - SPCM's for 1064 nm detection
- Used with Right Side Box

CPL Detector Box

- 2 - 532 Power Splitters
- 4 - SPCM's for 532 nm detection
- 2 - SPCM's for 1064 nm detection
- 2 - PMT's for 355 nm detection
- Independent use

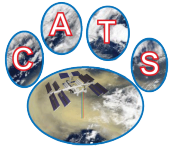
Right Side Detector Box

- 2 - 532 Power Splitters
- 4 - SPCM's for 532 nm detection
- 2 - SPCM's for 1064 nm detection
- Used with Left Side Box

HSRL Detector Box

- HSRL optic train with etalon and etalon electronics
- 10 - SPCM's for 532 nm HSRL detection
- 2 - SPCM's for 1064 nm detection
- Independent use

All boxes are fiber-coupled to telescope.

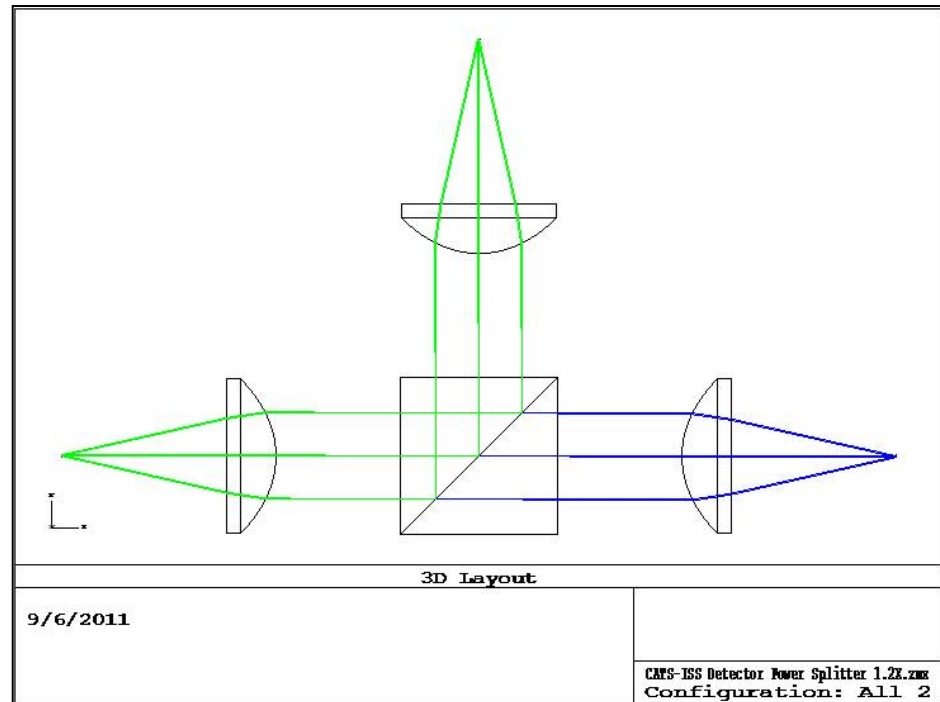


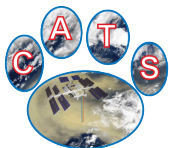
532 nm Power Splitters

64

The 532 nm return background is higher than what we want to drive the SPCM's at so we will divide the signal with a power splitter.

- 200 μm , 0.22 NA input fiber
- 300 μm , 0.22 NA output fiber
- Same lenses in all places
- 50/50 power beam splitter cube

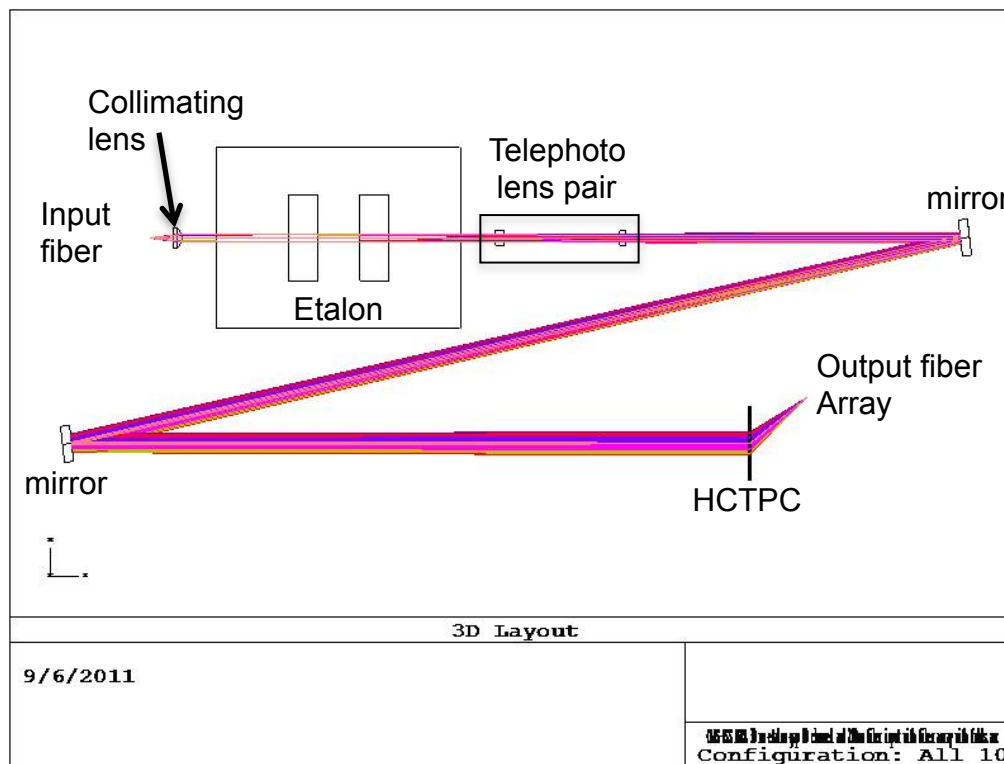


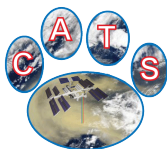


HSRL Optical Layout

65

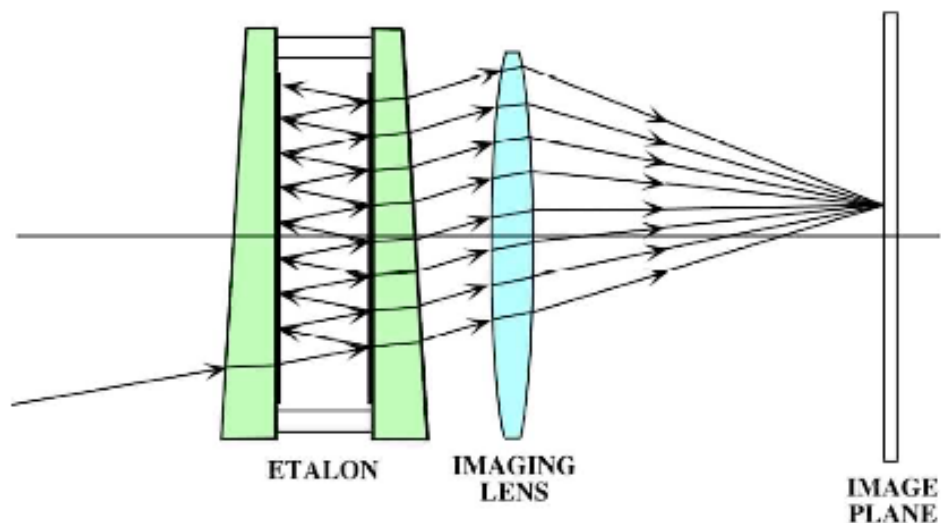
- 200 μm , 0.12 N.A. fiber input
- Collimate to 9.23 mrad to fill 1.2 orders
- 6 mm etalon CA with 3 cm gap
- 1.54 meter efl telephoto lens pair
- 8.2 mm image size on Holographic Circle to Point Converter (HCTPC)
- HCTPC images 10 spots spaced 650 μm apart and 180 μm - 250 μm diameter
- Image into 300 μm 0.37 N.A. fiber array
- 10 individual fiber coupled SPCM detectors used



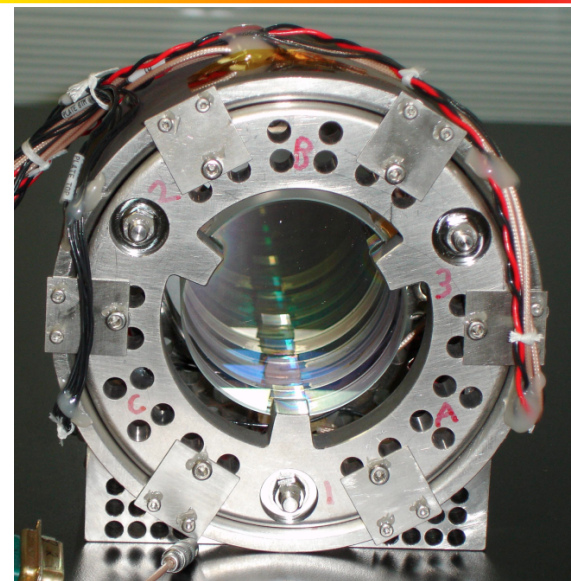


Etalon

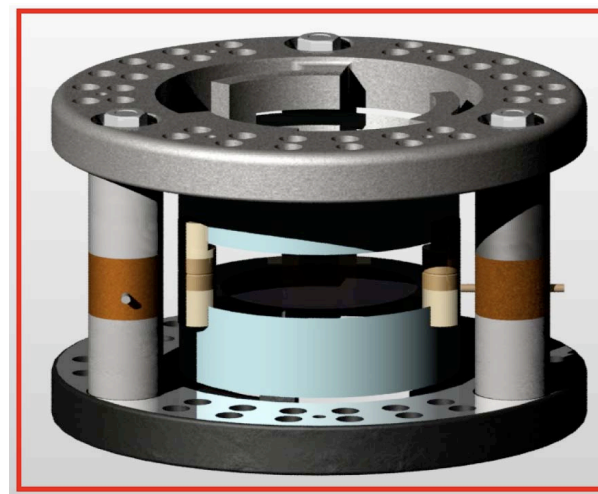
66



- Fabry-Perot interferometer (etalon) is merely two flat optical plates, with partially reflective coatings, held perfectly parallel with three posts. Typically the posts are piezo-tunable to control the spacing.
- provides spectral resolution needed for HSRL measurement
- housed in sealed box
 - thermal considerations
 - electrical (HV present, 500V 10 μ Amps)
 - similar units have been flight qualified



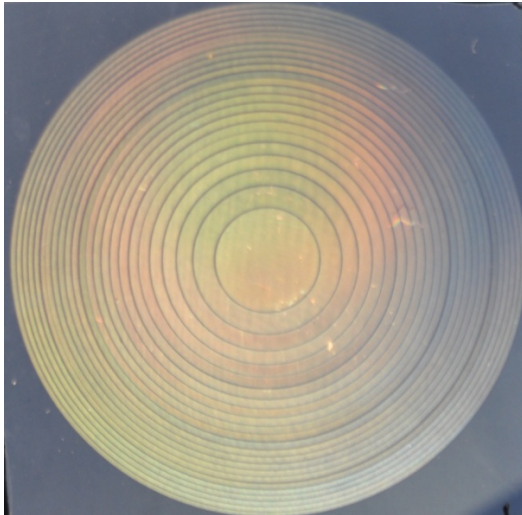
Prototype etalon, in Invar mount





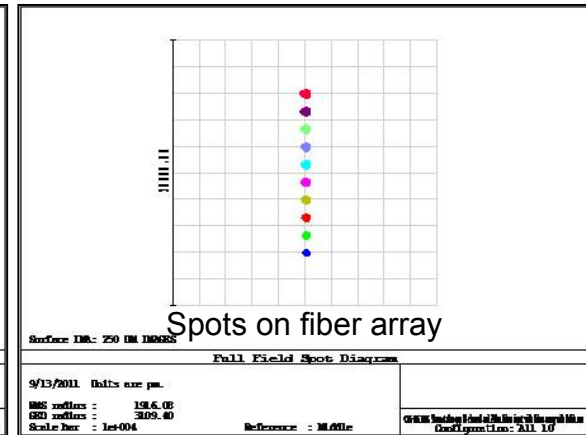
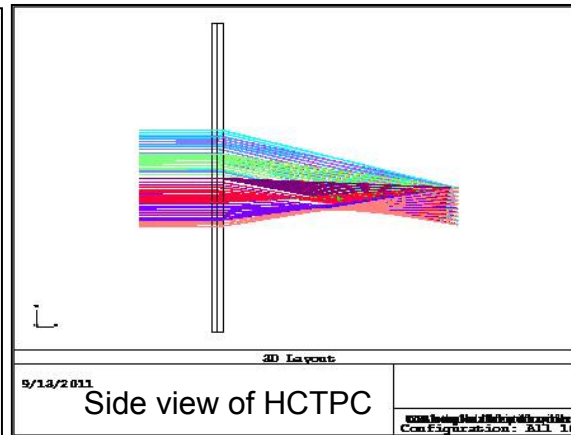
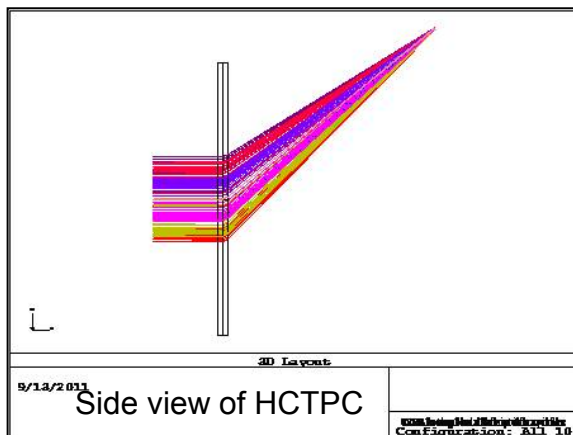
Holographic Circle-to-Point Converter

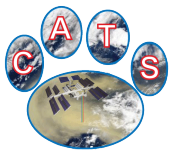
67



24 channel HCTPC that we plan to fly.

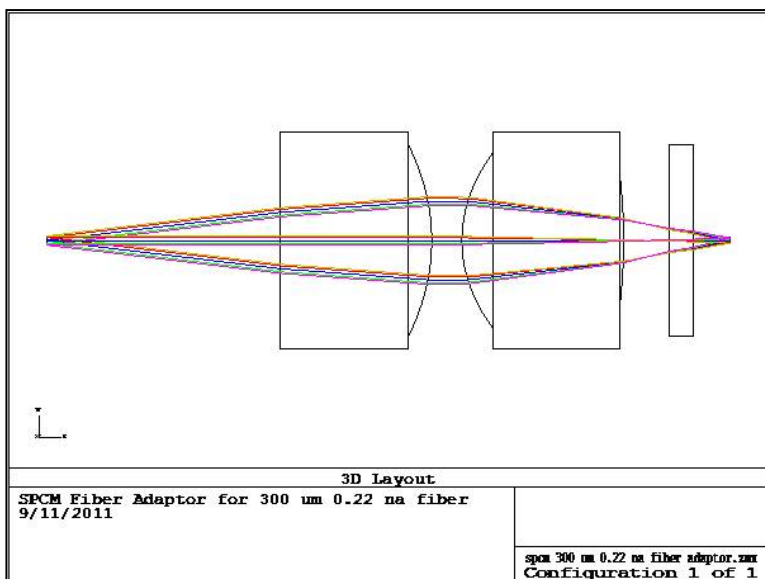
- The Holographic Circle to Point Converter (HCTPC) is an optic that acts as a series of co-centric lenses.
- Each lens on the HCTPC has equal area.
- Each lens focuses to a separate spot separated by $650 \mu\text{m}$.
- The HCTPC was designed for use with nearly collimated 532 nm light and has a 50 mm focal length.
- We will use the 10 center channels.
- We will focus the HCTPC output into a linear fiber array.





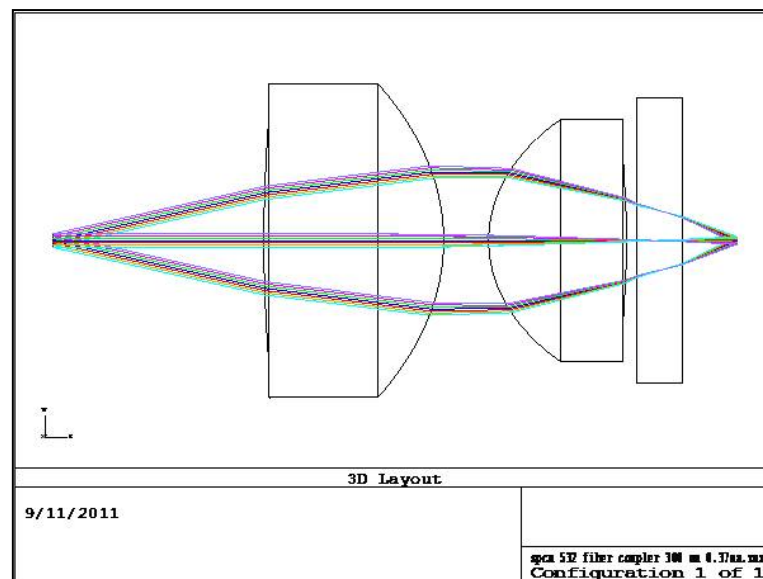
SPCM Coupling

68



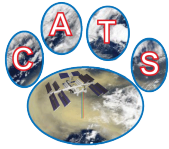
SPCM fiber coupler:

- 300 μm 0.22 N.A. input fiber
- 11.2 mm efl input lens
- 6.24 mm efl output lens
- 180 μm image size (300 μm input)



HSRL SPCM fiber array coupler:

- 300 μm 0.37 N.A. input fiber
- 6.75 mm efl input lens
- 4.0 mm efl output lens
- 168 μm image size



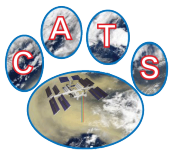
SPCM Detectors

69

- Used for 532 nm and 1064 nm detection
- Excelitas SPCM-AQRH-15 (formerly Perkin Elmer)
- +5 volts in.
- 15 MHz count rates with TTL outputs.
- ~60% Q.E. At 532nm
- 1-2% Q.E at 1064nm
- 180 μm active area
- Will need one for each channel, 30 total.
- We will modify the packaging to survive vibration testing.



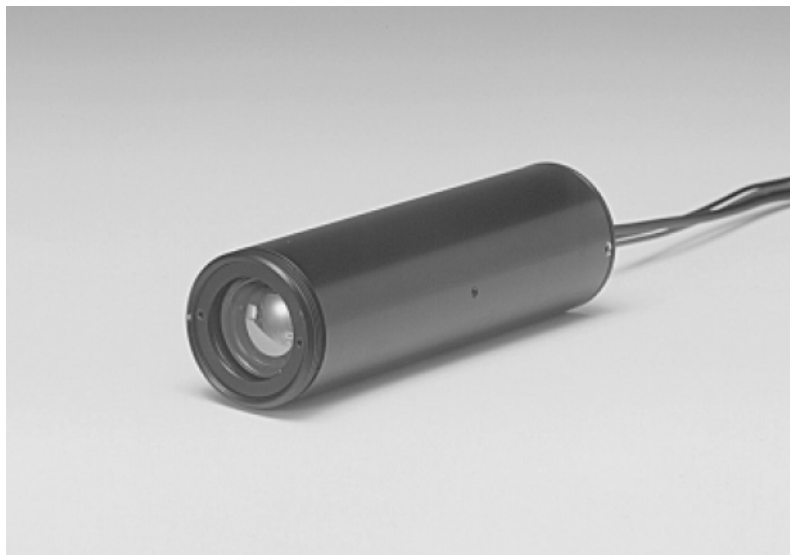
Single Photon
Counting Module (SPCM)

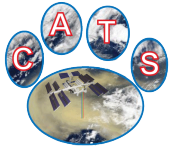


355 nm PMT Detectors

70

- Hamamatsu H7360-1
- +5 Volts in
- TTL counts out
- 20 MHz count rate
- ~30% Q.E.
- Large active area
- We will modify the packaging to survive vibration testing.





Predicted Transmitter Throughput

71

Transmitter

Laser 1 Right Side Path	532	1064
fold mirror	99%	99%
10X BX	98%	98%
Power beam splitter	49%	49%
Controlled Risley 1	99%	99%
Controlled Risley 2	99%	99%
Alignment Risley 1	99%	99%
Alignment Risley 2	99%	99%
2.25X BX	98%	98%
	45%	45%

Laser 1 Left Side Path	532	1064
fold mirror	99%	99%
10X BX	98%	98%
Power beam splitter	49%	49%
fold mirror	99%	99%
Controlled Risley 1	99%	99%
Controlled Risley 2	99%	99%
Alignment Risley 1	99%	99%
Alignment Risley 2	99%	99%
2.25X BX	98%	98%
	44%	44%

Laser 2 HSRL	532	1064
Translation mirror	99%	99%
10X BX	98%	98%
fold mirror	99%	99%
Controlled Risley 1	99%	99%
Controlled Risley 2	99%	99%
Alignment Risley 1	99%	99%
Alignment Risley 2	99%	99%
2.25X BX	98%	98%
Channel Select R1	99%	99%
Channel Select R2	99%	99%
	89%	89%

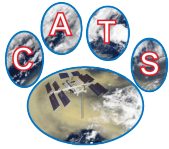
Laser 2 CPL	532	1064	355
fold mirror	99%	99%	-----
THG	-----	-----	-----
10X BX	98%	98%	98%
Energy Monitor	99%	99%	99%
fold mirror	99%	99%	99%
Controlled Risley 1	99%	99%	99%
Controlled Risley 2	99%	99%	99%
Alignment Risley 1	99%	99%	99%
Alignment Risley 2	99%	99%	99%
3.75X BX	98%	98%	98%
	90%	90%	90%

Laser 1 Right Side Path	532	1064
Laser Output Energy (mJ)	2.5	2.5
Transmitter Output Energy (mJ)	1.1	1.1

Laser 1 Left Side Path	532	1064
Laser Output Energy (mJ)	2.5	2.5
Transmitter Output Energy (mJ)	1.1	1.1

Laser 2 HSRL	532	1064
Laser Output Energy (mJ)	3.0	3.0
Transmitter Output Energy (mJ)	2.7	2.7

Laser 2 CPL	532	1064	355
Laser Output Energy (mJ)	2.0	2.0	2.0
Transmitter Output Energy (mJ)	1.8	1.8	1.8



Predicted Receiver Throughput

72

Receiver

Right Side Path	532 paths	1064 paths
Telescope	78.5%	78.5%
Field Corrector L1	99%	99%
Field Corrector L2	99%	99%
Field Corrector L3	99%	99%
Collimating Lens	99%	99%
Fold Mirror	99%	99%
532R/ 1064T Dichroic	98%	97%
Fold Prism	99%	
Band Pass Filter 1	60%	70%
Band Pass Filter 2	60%	70%
1/2 waveplate	99%	99%
polarization cube	99%	99%
Fold Prism	99%	99%
Focus Lens	99%	99%
200um 0.22 na fiber	94%	94%
Power Splitter L1	99%	
Power Splitter Cube	49%	
Power Splitter L2	99%	
300um 0.22 na fiber	94%	
SPCM Coupler L1	99%	99%
SPCM Coupler L2	99%	99%
	10.4%	31.4%

Left Side Path	532 paths	1064 paths
Telescope	78.5%	78.5%
Field Corrector L1	99%	99%
Field Corrector L2	99%	99%
Field Corrector L3	99%	99%
Collimating Lens	99%	99%
Fold Mirror	99%	99%
532R/ 1064T Dichroic	98%	97%
Fold Prism	99%	
Band Pass Filter 1	60%	70%
Band Pass Filter 2	60%	70%
1/2 waveplate	99%	99%
polarization cube	99%	99%
Fold Prism	99%	99%
Focus Lens	99%	99%
200um 0.22 na fiber	94%	94%
Power Splitter L1	99%	
Power Splitter Cube	49%	
Power Splitter L2	99%	
300um 0.22 na fiber	94%	
SPCM Coupler L1	99%	99%
SPCM Coupler L2	99%	99%
	10.4%	31.4%

HSRL	532	1064 paths
Telescope	78.5%	78.5%
Field Corrector L1	99%	99%
Field Corrector L2	99%	99%
Field Corrector L3	99%	99%
Collimating Lens	99%	99%
Fold Mirror	99%	99%
532R/ 1064T Dichroic	98%	97%
Fold Prism	99%	
Band Pass Filter 1	60%	70%
Band Pass Filter 2		70%
1/2 waveplate	99%	99%
polarization cube	99%	99%
Fold Prism	99%	99%
Focus Lens	99%	99%
200um 0.22 na fiber		94%
200um 0.12 na fiber	94%	
HSRL Collimating Lens	99%	
Etalon	75%	
Telephoto lens pair	98%	
Fold Mirrors	98%	
HCTPC	75%	
SPCM Coupler L1	99%	99%
SPCM Coupler L2	99%	99%
	20.5%	31.4%

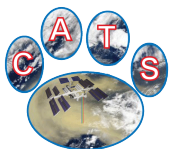
CPL Path	532 paths	1064 paths	355 paths
Telescope	78.5%	78.5%	78.5%
Field Corrector L1	99%	99%	99%
Field Corrector L2	99%	99%	99%
Field Corrector L3	99%	99%	99%
Collimating Lens	99%	99%	99%
Fold Mirror	99%	99%	99%
355R/ 532,1064T Dichroic	98%	97%	98%
Fold Prism			99%
532R/ 1064T Dichroic	98%	97%	
Fold Prism	99%		
Band Pass Filter 1	60%	70%	50%
Band Pass Filter 2	60%	70%	50%
1/2 waveplate	99%	99%	99%
polarization cube	99%	99%	99%
Fold Prism	99%	99%	99%
Focus Lens	99%	99%	99%
200um 0.22 na fiber	94%	94%	94%
Power Splitter L1	99%		
Power Splitter Cube	49%		
Power Splitter L2	99%		
300um 0.22 na fiber	94%		
SPCM Coupler L1	99%	99%	99%
SPCM Coupler L2	99%	99%	99%
	10.2%	30.4%	16.0%

Right Side Path	532 paths	1064 paths
532 has two detectors per channel so multiply transmission by 2	20.8%	31.4%

Left Side Path	532 paths	1064 paths
532 has two detectors per channel so multiply transmission by 2	20.8%	31.4%

HSRL	532	1064 paths
HSRL is split over 10 channels. The total for the 10 is shown.	20.5%	31.4%

CPL Path	532 paths	1064 paths	355 paths
532 has two detectors per channel so multiply transmission by 2	20.4%	30.4%	16.0%



Alignment Budget

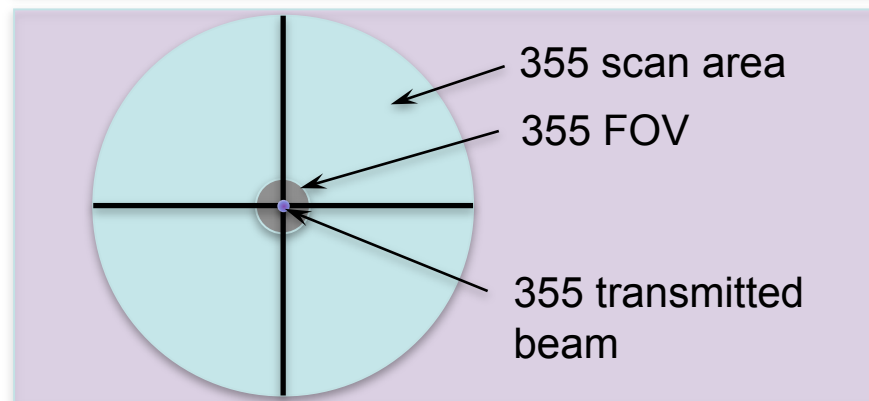
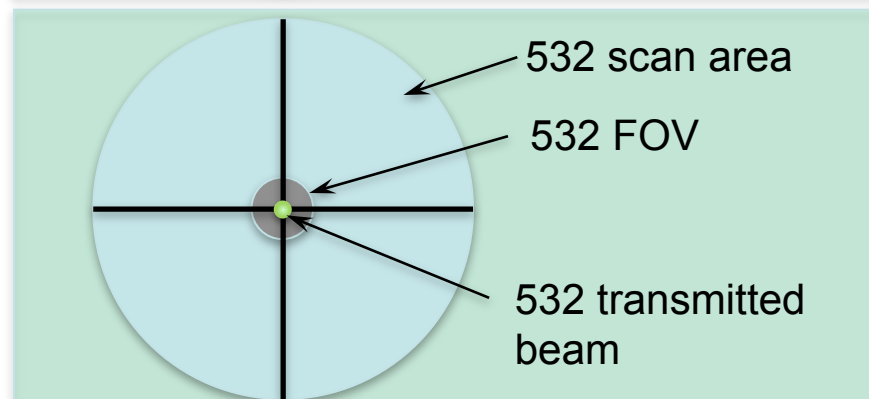
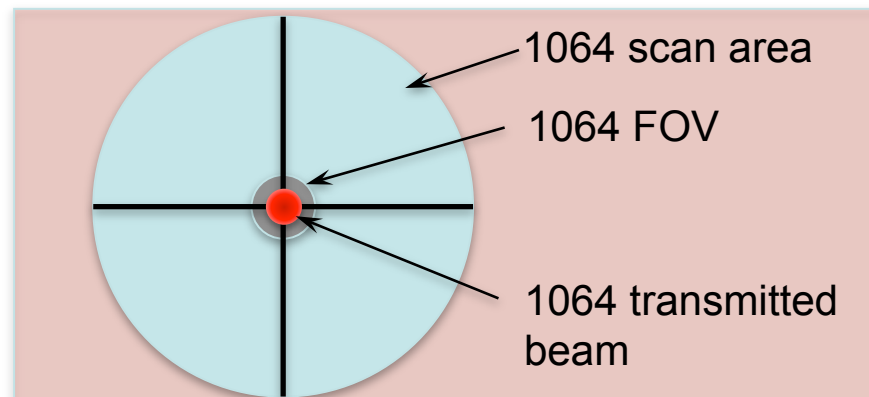
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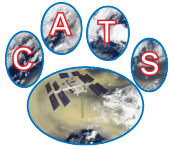
Transmitter Divergence ($1/e^2$)	532 nm	1064 nm	355 nm
Laser 1 Right Side	33 +/- 5 μ rad	67 +/- 9 μ rad	-----
Laser 1 Left Side	33 +/- 5 μ rad	67 +/- 9 μ rad	-----
Laser 2 HSRL	33 +/- 5 μ rad	67 +/- 9 μ rad	-----
Laser 2 CPL	33 +/- 5 μ rad	67 +/- 11 μ rad	23 +/- 4 μ rad

Receiver IFOV (FWHM)	532 nm	1064 nm	355 nm
Right Side	113 +/- 4 μ rad	117 +/- 4 μ rad	-----
Left Side	113 +/- 4 μ rad	117 +/- 4 μ rad	-----
HSRL	113 +/- 4 μ rad	117 +/- 4 μ rad	-----
CPL	113 +/- 4 μ rad	117 +/- 4 μ rad	103 +/- 4 μ rad

Margine	532 nm	1064 nm	355 nm
Right Side	40 +/- 4.5 μ rad	25 +/- 6.5 μ rad	-----
Left Side	40 +/- 4.5 μ rad	25 +/- 6.5 μ rad	-----
HSRL	40 +/- 4.5 μ rad	25 +/- 6.5 μ rad	-----
CPL	40 +/- 4.5 μ rad	25 +/- 7.5 μ rad	40 +/- 4 μ rad

In Flight Adjustability	532 nm	1064 nm	355 nm
Right Side	~ 700 μ rad	~ 700 μ rad	-----
Left Side	~ 700 μ rad	~ 700 μ rad	-----
HSRL	~ 700 μ rad	~ 700 μ rad	-----
CPL	~ 700 μ rad	~ 700 μ rad	~ 700 μ rad

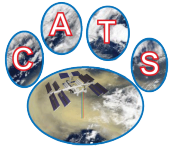




Major Milestones

74

- Place the order for the telescope. 05/13/2011
- Order the filters. 08/08/2011
- Telescope PDR. 09/15/2011
- Instrument PDR. 09/20/2011
- *Modify and vibe test the detectors.* 10/10/2011
- *Telescope CDR* 10/10/2011
- *Order the long lead optics.* 10/15/2011
- *Vibe test the Newport stages.* 10/17/2011
- *Complete STOP analysis.* 12/15/2011
- *Check the stray light due to the instrument doors.* 12/30/2011
- *Instrument CDR* 01/10/2012
- *Build the detector fiber adaptors* 03/01/2012
- *Build the Aft-optics.* 05/02/2012
- *Build and test the beam expanders.* 06/02/2012
- *Assemble the transmitter path.* 08/24/2012
- *Receive the telescope.* 09/03/2012



Optics Summary

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- Laser development by Fibertek is on schedule.
- Telescope development by Axsys is on schedule.
- Preliminary optical design is done.
- Optical analysis is underway.
- Modifications of detectors for flight has started.
- On track for CDR in January.



Mechanical Design

William Mamakos
Jeff Guzek

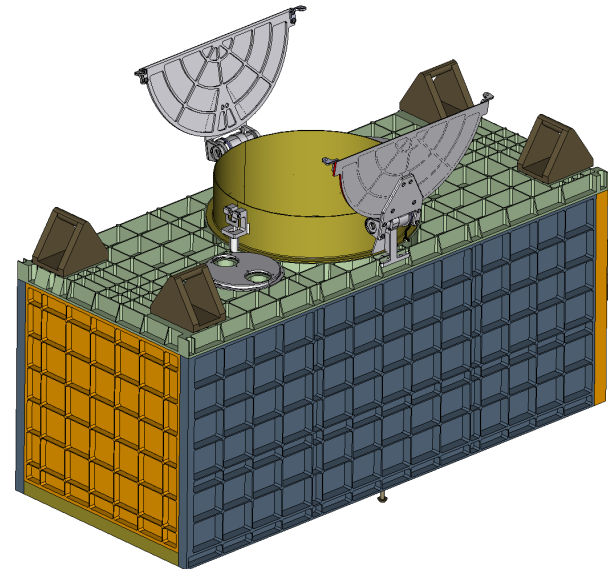
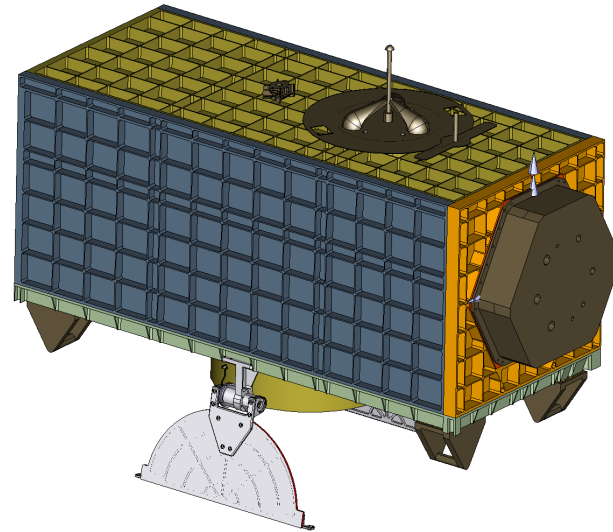
Design Interface Inc.

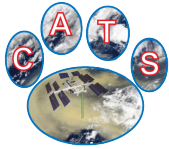


Mechanical Summary

77

- General Requirements
- Payload Overview
- Interfaces
- Instrument Overview
- Materials
- Future Work

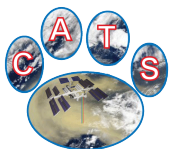




General Requirements

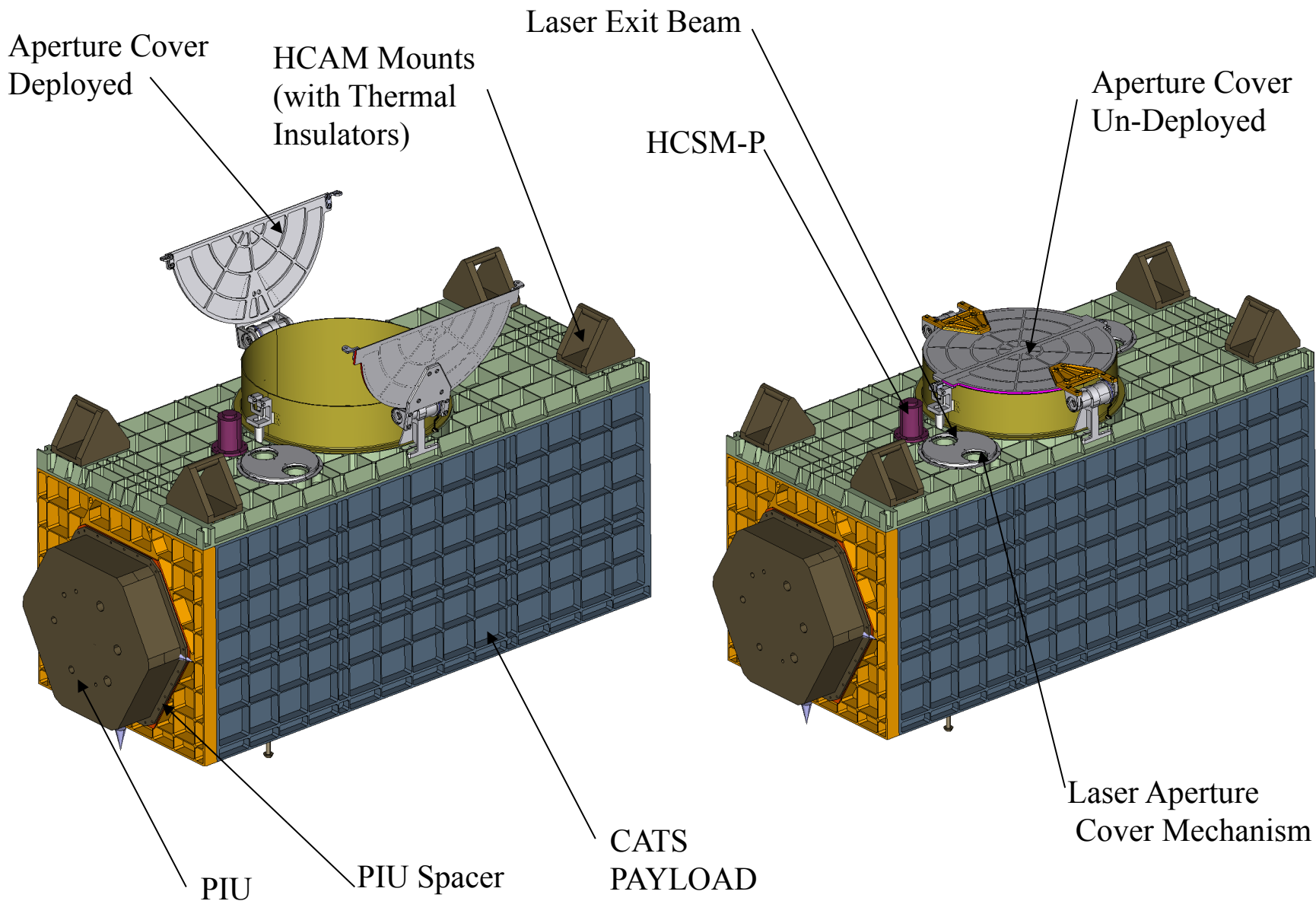
78

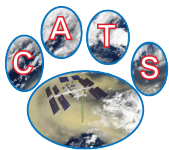
- Driving Design Documents
 - NASDA-ESPC-2563 (*JEM Payload Accommodation Handbook*)
 - NASDA-ESPC-2857 (*HTV Cargo Standard Interface Requirements Document*)
 - NASDA-ESPC-3122 (*Payload Interface Unit Product Specification*)
 - ICD-2-19001 Sec 14 (*Payload Deployment and Retrieval System*)
 - SSP 42004 (*MMS User Interface Control Document*)
 - NTS 1700.7B (*Safety Policy & Requirements for Payloads using the Space Transportation System*)
 - Mechanical Systems Working Group/Design for Minimum Risk (DFMR) requirements
 - CATS has no Safety Critical Mechanisms
 - Mass: <500 kg
 - Volume: Defined in NASDA-ESPC-2857



CATS Payload Overview

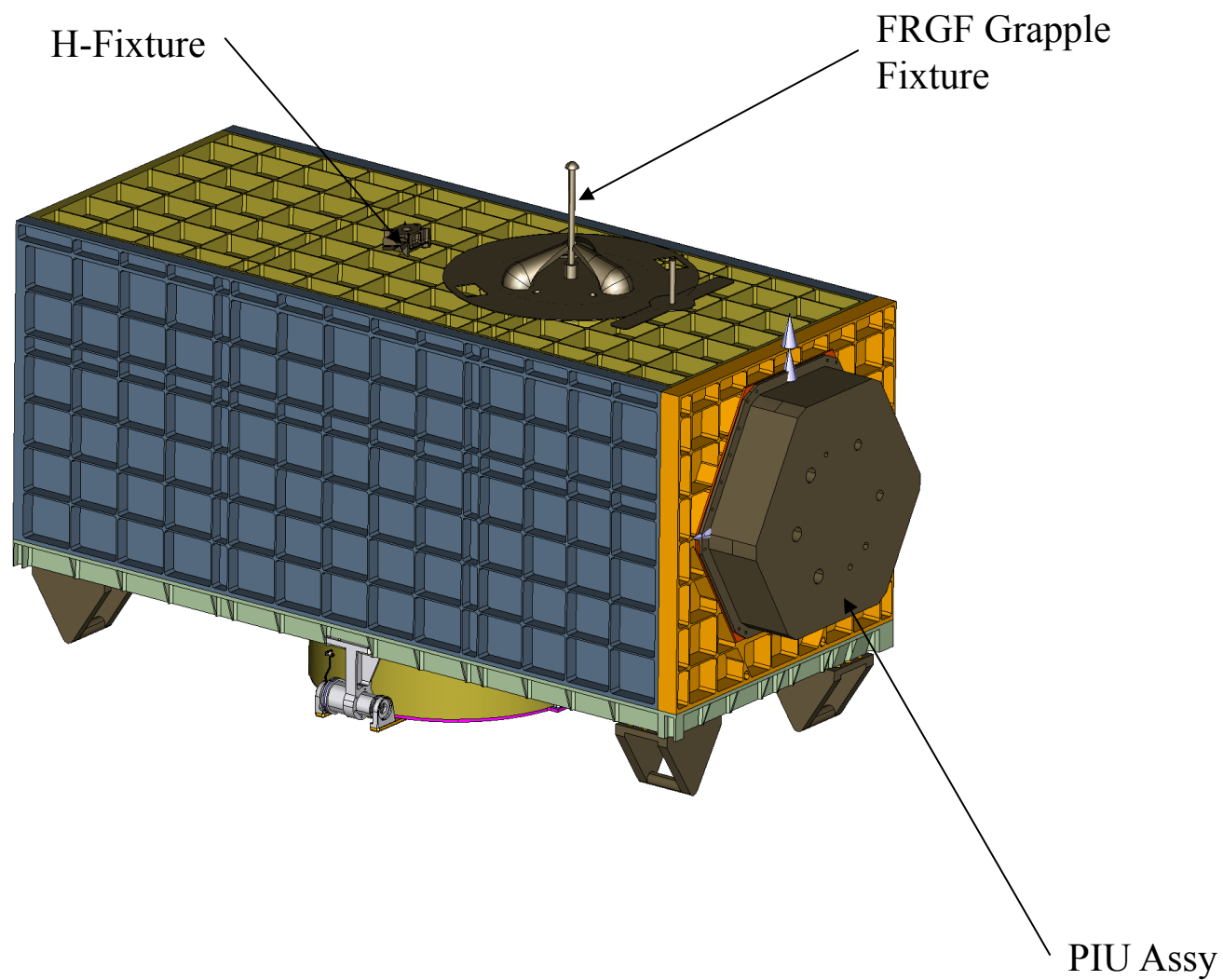
79

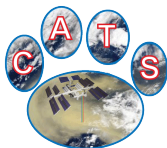




CATS Payload Overview

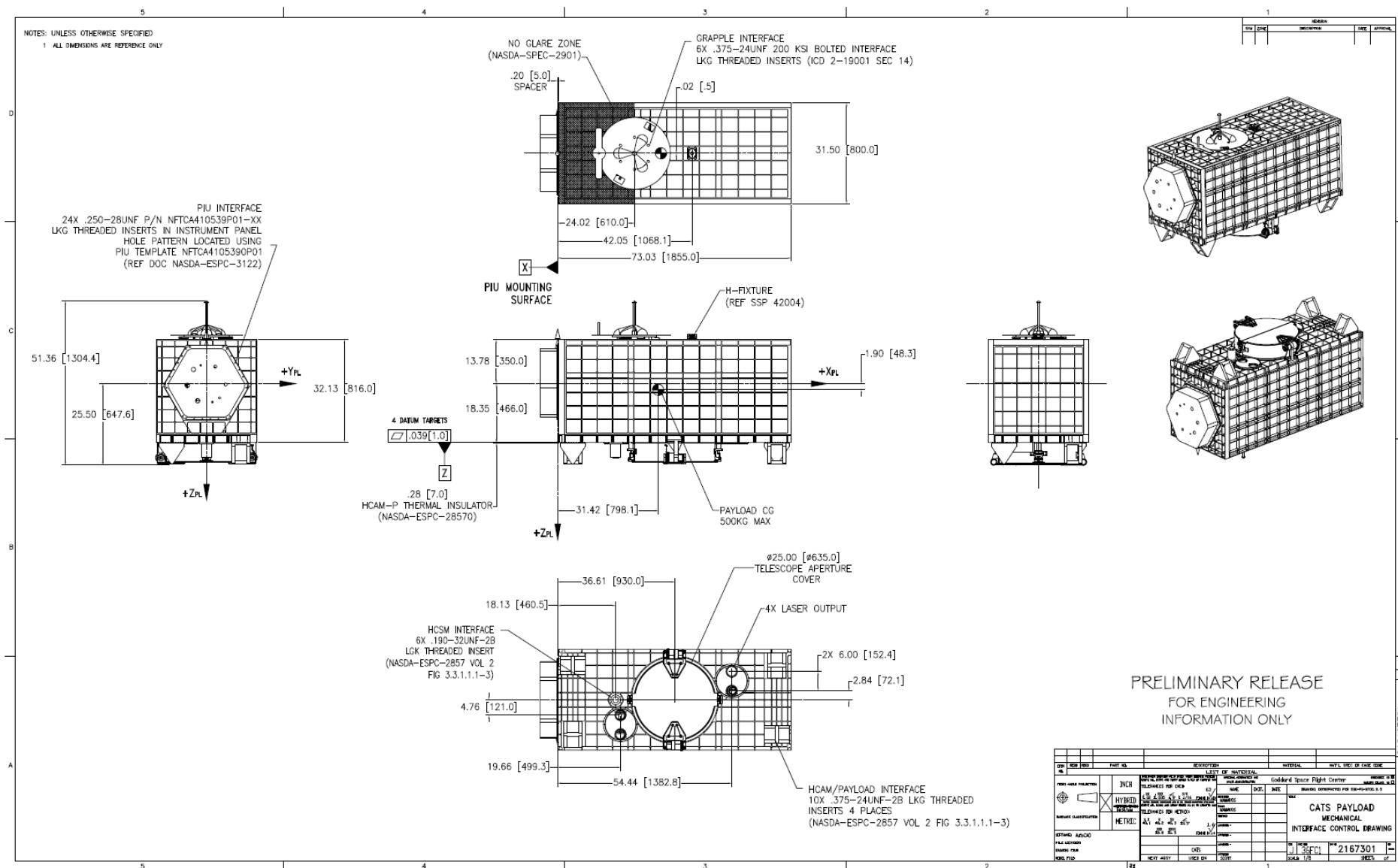
80

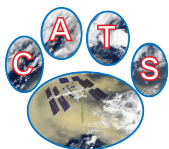




CATS Payload MICD

81



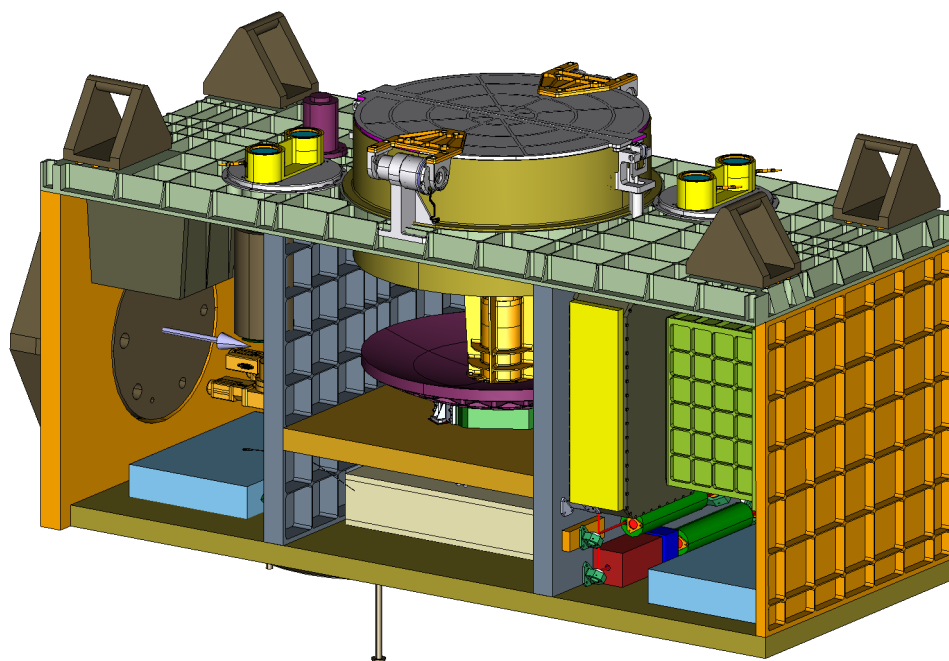


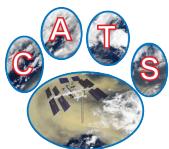
Instrument Overview

82

• Main Instrument Payload Components

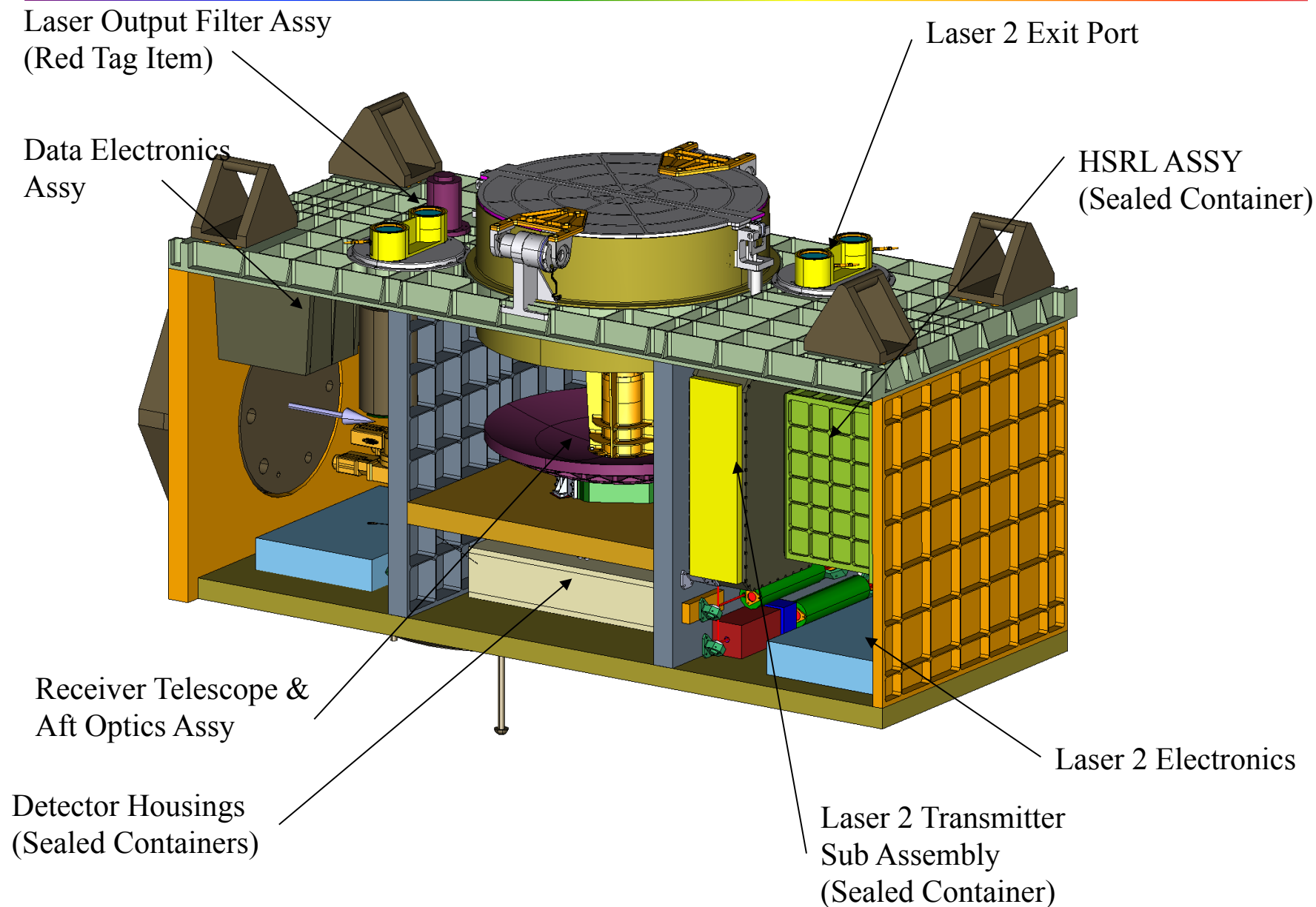
- Laser Transmitter Assembly
 - Fibertek
 - separate laser electronics
- Telescope Receiver Sub Assembly
 - Be telescope (AXSYS)
 - aft optics assembly
- Detector Assembly(s)
 - sealed volume(s)
 - cold plate
- HSRL
 - 12 detectors
 - etalon
 - cold plate
 - sealed container
- Main Electronics
 - Fibertek
 - cold plate
- Power Converter
 - Fibertek
 - cold plate
- Telescope Cover
 - contamination protection
 - stepper motor (redundant windings)
 - launch lock (HOP)
- Laser Output Cover
 - contamination protection
 - stepper motor (redundant windings)
 - laser output filter interface (red tag)

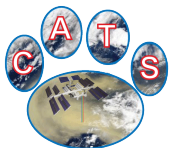




CATS Payload Components

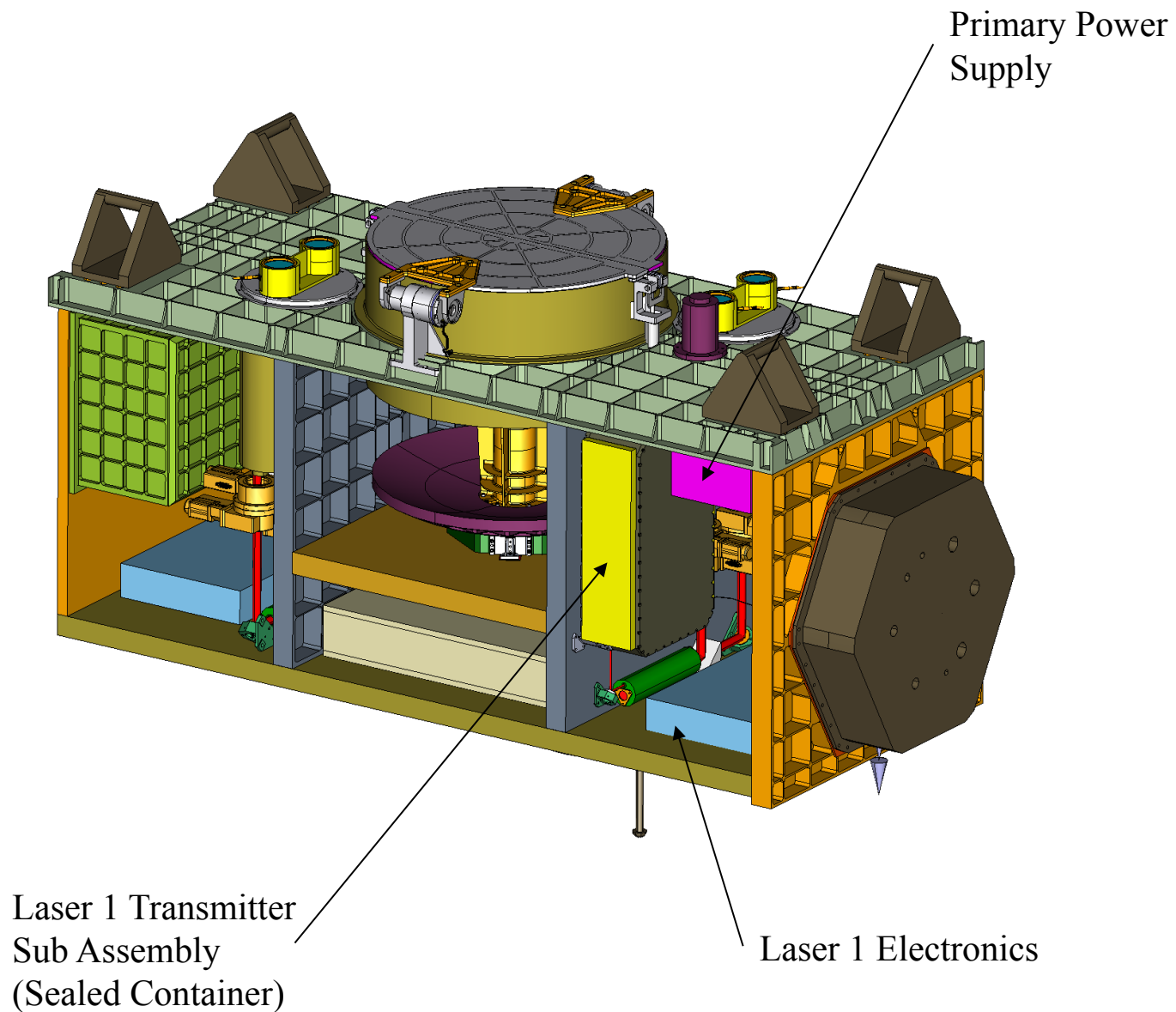
83

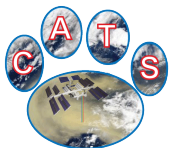




CATS Payload Components

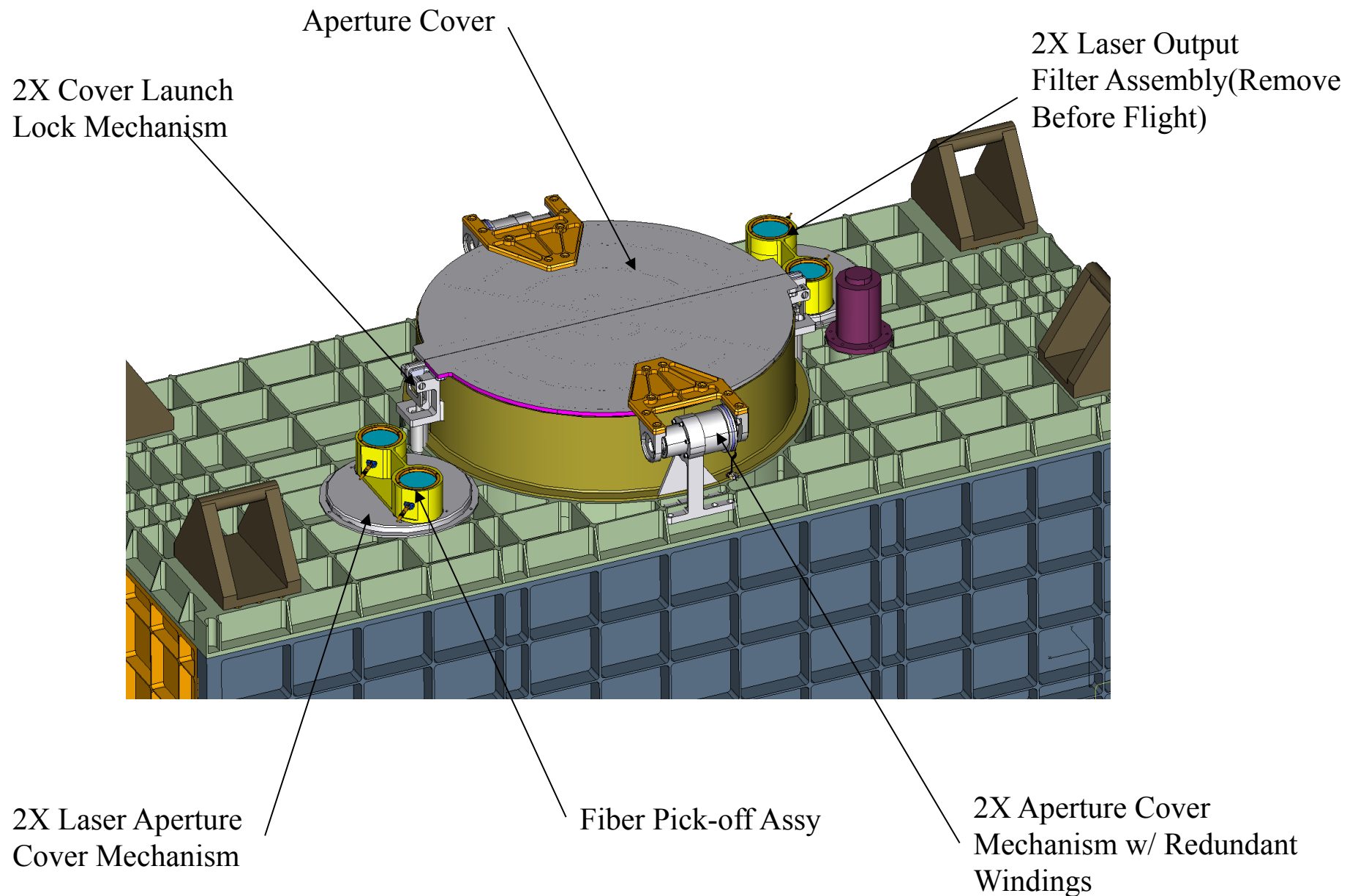
84





CATS Aperture Overview

85

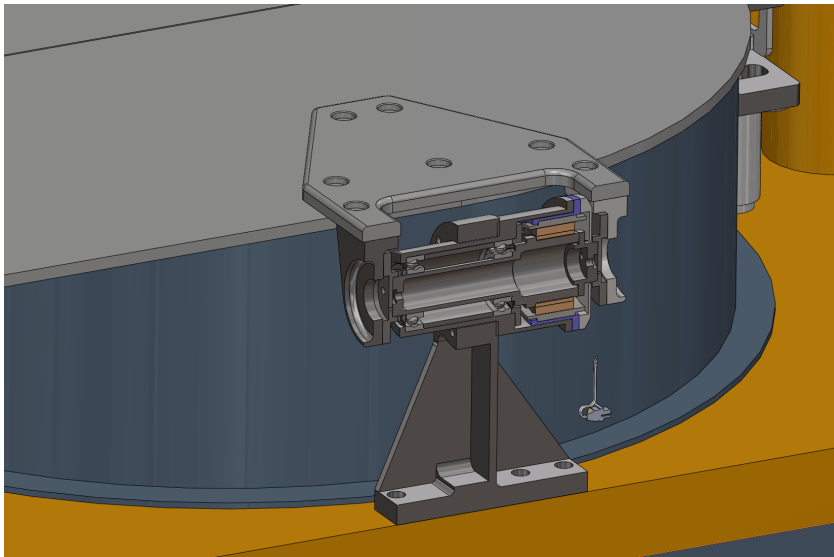




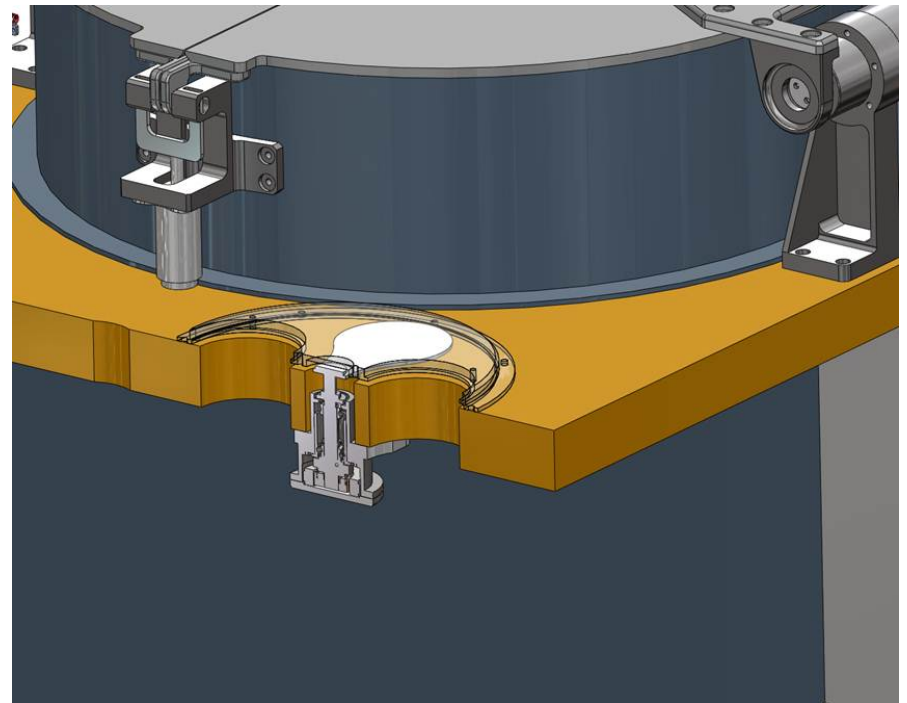
Main Door Motor Assembly

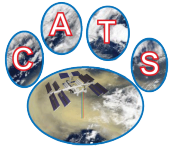
86

- Telescope Aperture Cover



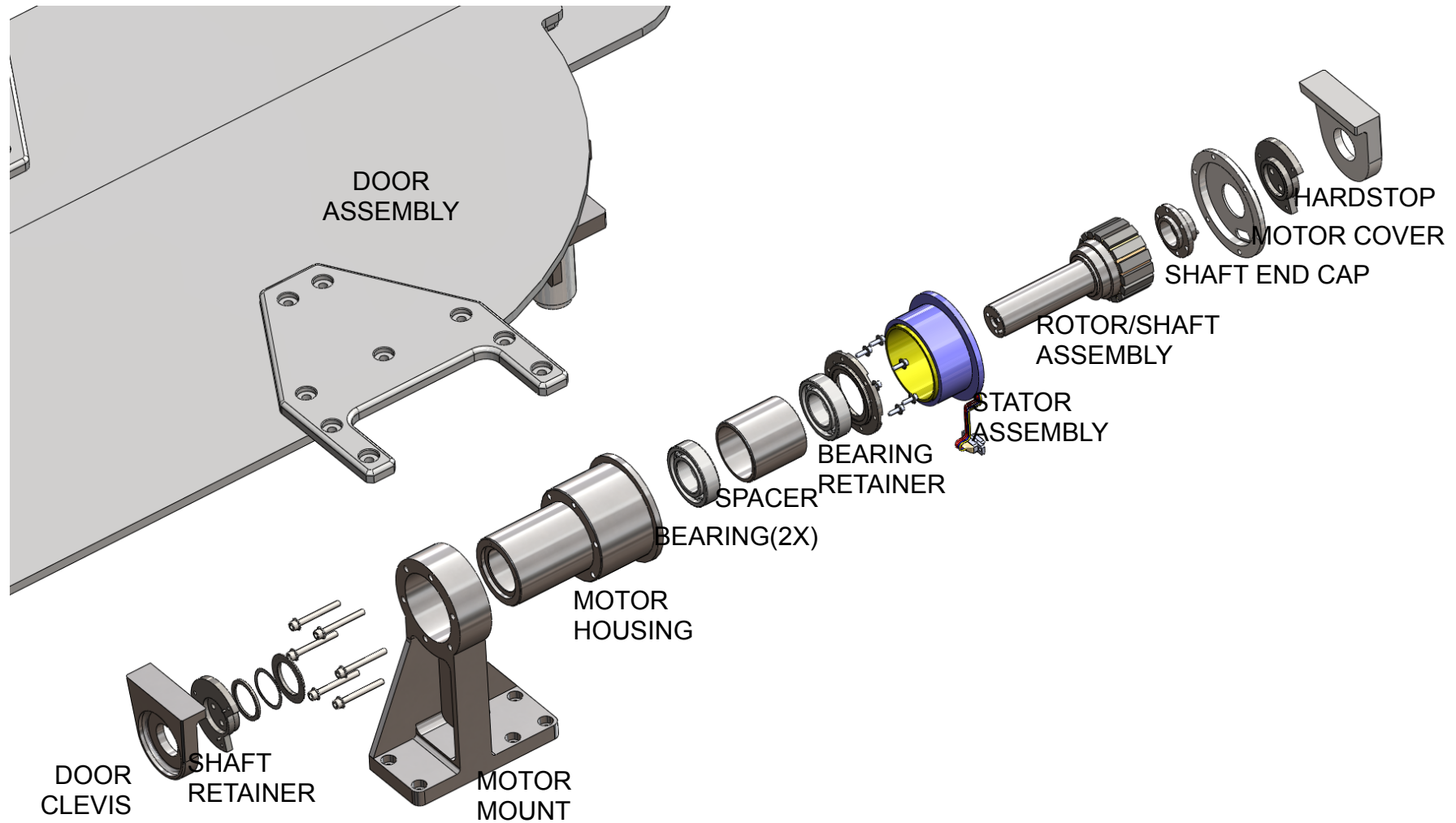
- Laser Output Cover

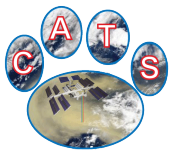




Door Mechanism Concept

87



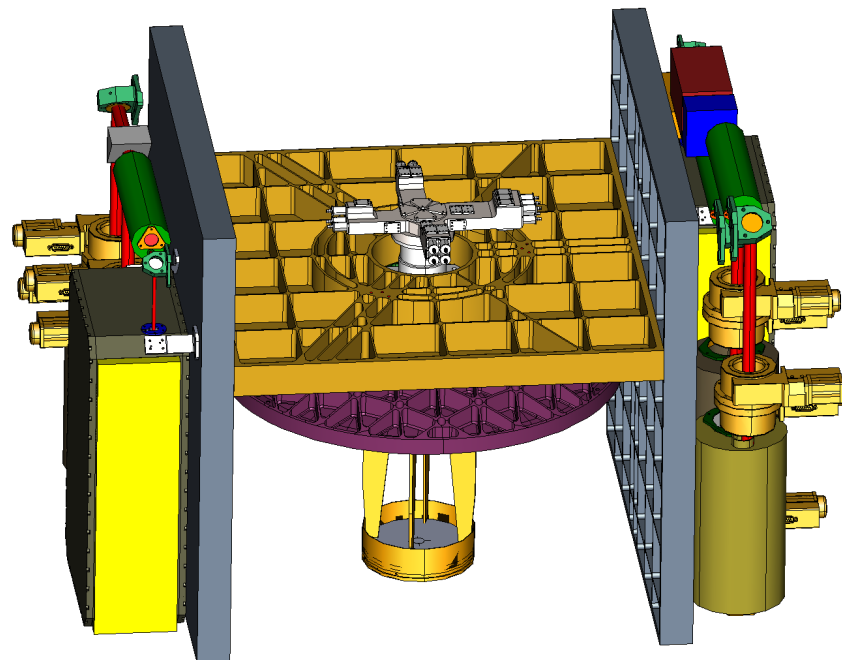


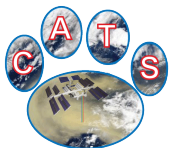
Instrument Overview

88

- Receiver/Transmit Sub Assembly

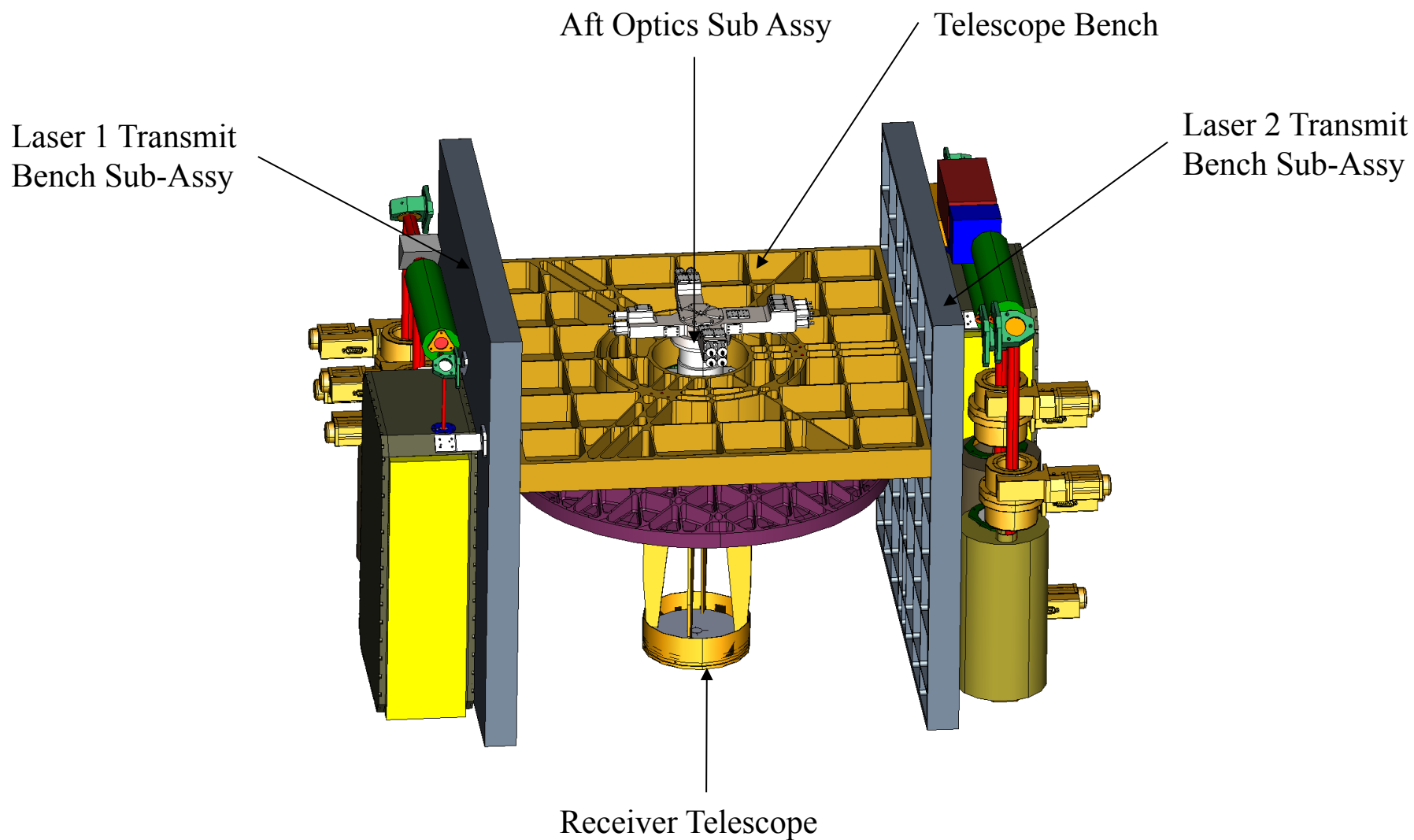
- Laser Transmitter
 - Fibertek
 - Sealed Container
- Laser Electronics
 - Fibertek
 - Sealed Container
- Receiver Telescope
 - AXSYS
 - Beryllium
- Aft Optic
 - Titanium Housing
 - Similar Optical Packaging used on GLAS Lasers
 - Fiber Coupled
- Detector Assembly
 - Sealed Container
 - COTS Detectors
- Laser Transmit Path Assembly
 - COTS Risley Mechanisms
 - COTS Translation Stage
 - Off Axis BX(s)
 - THG (Fibertek)
 - Similar Optical Packaging used on GLAS LASERS

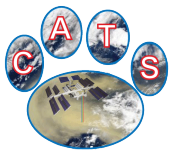




Receiver/Transmit Subassembly

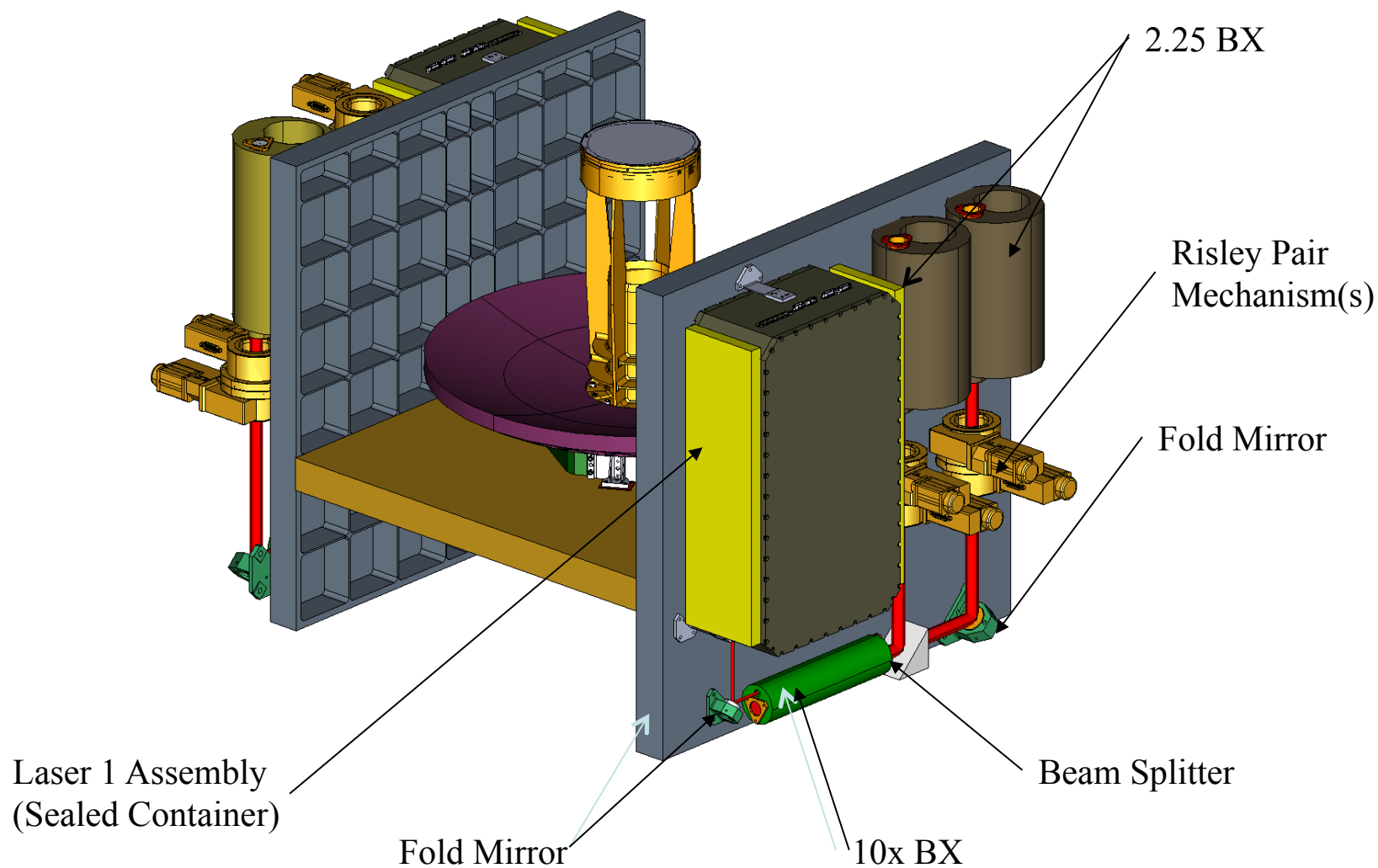
89

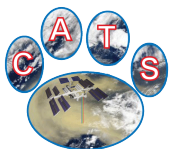




Laser 1 Transmit Path Subassembly

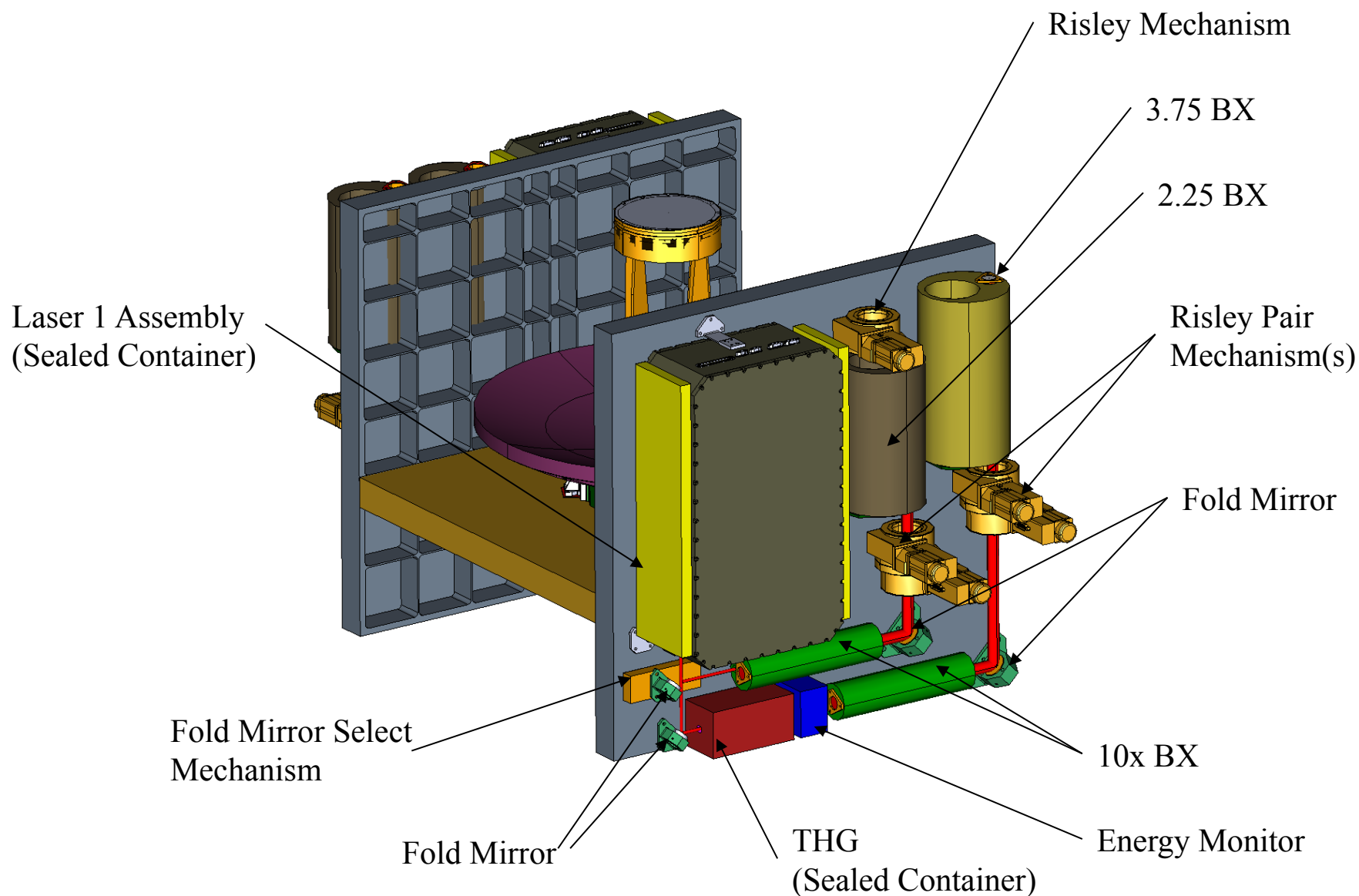
90

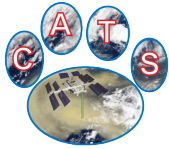




Laser 2 Transmit Path Subassembly

91





Mass Properties

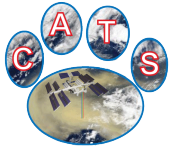
92

PART DESCRIPTION	QTY	Mass lbs	Mass kg	Total Mass lbs	Total Mass kg
PIU PLATE	1	36.98	16.79	36.98	16.79
STRUCTURAL PANEL +X	1	12.03	5.46	12.03	5.46
STRUCTURAL PANEL +Y	1	32.69	14.84	32.69	14.84
STRUCTURAL PANEL +Z	1	47.34	21.49	47.34	21.49
STRUCTURAL PANEL -Y	1	32.69	14.84	32.69	14.84
STRUCTURAL PANEL -Z	1	140.95	63.99	140.95	63.99
LASER 1 BENCH	1	15.73	7.14	15.73	7.14
LASER 2 BENCH	1	15.73	7.14	15.73	7.14
TELESCOPE BENCH	1	13.16	5.97	13.16	5.97
			0.00	0.00	0.00
AFT OPTICS ASSY	1	8.10	3.68	8.10	3.68
RECEIVER TELESCOPE	1	23.76	10.79	23.76	10.79
BEAM EXPANDER 10X	3	4.00	1.82	12.00	5.45
BEAM EXPANDER 2.25X	3	4.00	1.82	12.00	5.45
BEAM EXPANDER 3.75X	1	5.00	2.27	5.00	2.27
RISLEY MECHANISM	9	3.96	1.80	35.64	16.18
TRANSLATION STAGE	1	2.00	0.91	2.00	0.91
THG ASSY	1	3.00	1.36	3.00	1.36
FOLD MIRROR MOUNT	6	1.00	0.45	6.00	2.72
SUN SHIELD	1	6.10	2.77	6.10	2.77
DOOR MECHANISM ASSY	1	25.00	11.35	25.00	11.35
			0.00	0.00	0.00
HSRL ASSEMBLY	1	60.00	27.24	60.00	27.24
DETECTOR ASSY	1	45.00	20.43	45.00	20.43
LOM	2	60.00	27.24	120.00	54.48
LEM	2	10.25	4.65	20.50	9.31
DSEM ELECTRONICS	1	36.00	16.34	36.00	16.34
POWER ELECTRONICS	1	20.00	9.08	20.00	9.08
			0.00	0.00	0.00
PIU	1	63.80	28.97	63.80	28.97
HCAM	4	5.50	2.50	22.00	9.99
GRAPPLE	1	28.00	12.71	28.00	12.71
HSCM-P	1	5.00	2.27	5.00	2.27
H-FIXTURE	1	5.00	2.27	5.00	2.27
PIU SPACER	1	4.00	1.82	4.00	1.82
HARNESS	1	25.00	11.35	25.00	11.35
FASTENERS	1	10.00	4.54	10.00	4.54
BLANKETS	1	17.30	7.85	17.30	7.85
THERMAL SYSTEM	1	30.00	13.62	30.00	13.62

TOTAL:

997.50

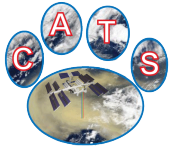
452.87



Materials List

93

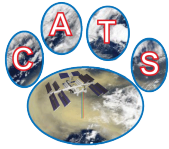
- Aluminum 6061-t651
 - Structural Components
 - Sub Assembly Housings
- Beryllium I-220
 - Receiver Telescope Assembly
- Titanium 6AL4V
 - Aft Optics Housing
 - Flexure Mounts
- Invar 30
 - Beam Expander Telescopes
- G-10
 - Thermal Isolators



Future Work

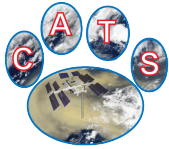
94

- Further Development of Sub System Assemblies
- Mass Optimization
- Interface definition with outside vendors
- Implement Higher Fidelity External Hardware (CAD) Models
- Thermal Control System
- Harness
- Verify Launch Vehicle & ISS Interfaces
- I & T Accommodation
- GSE
 - Alignment fixtures
 - Handling Fixtures
 - Dolly
 - Transportation Container



Mechanical & Structural

Nicholas Galassi / Aerostress, Inc.



Analysis Summary

96

Requirements

Factors of Safety

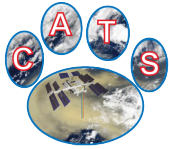
Material Properties

General Analysis Approach

Current CATS-ISS structure Analysis & Margins

Testing/Verification

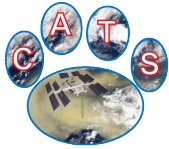
Future Work



General Requirements

97

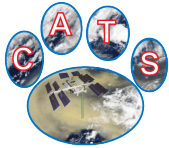
- General requirements levied from ISS FRAM Based Payload Common launch Interface Requirements Document (IRD) (SSP 57012)
- For use with all CATS-ISS instrument components:
 - Telescope
 - Lasers
 - Optical Mirror Assemblies
 - Electronics Boxes
 - HCAM Fittings
- Requirements document covers the following launch Loads:
 - Component fundamental frequency minimums
 - Component loading levels (quasi-static, acoustic, shock, vibration, etc.)
 - Venting profile
 - Testing: qualification levels, load factors, and test duration
- Additional Loads
 - On-Orbit Loads
 - Crew Applied Loads (EVA)



General Requirements (con't)

98

- Stiffness
 - 50 Hz minimum frequency constrained at HCAM fittings
 - 5 Hz minimum frequency constrained at PIU
- Mass
 - 500 kg maximum



General Requirements (con't)

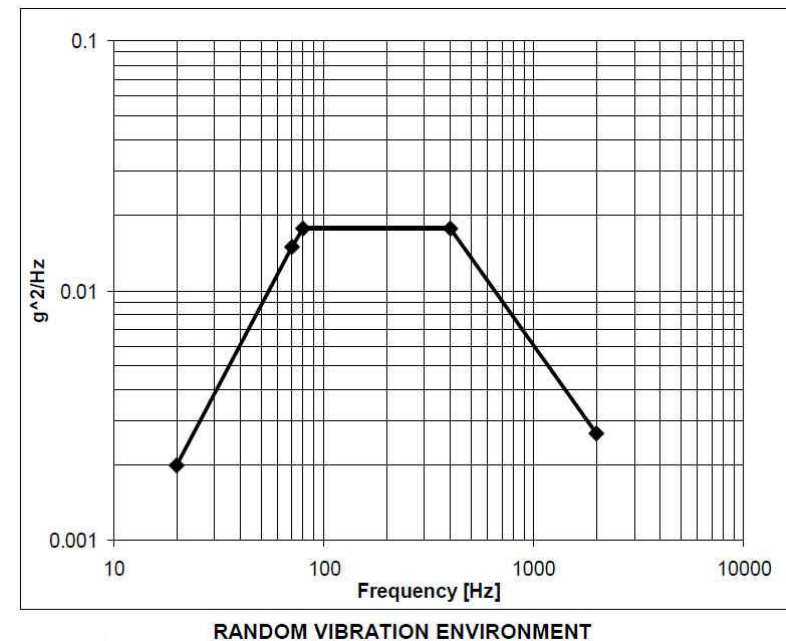
99

• Quasi-static Design Loads

TX (g) (T1)	TY (g) (T2)	TZ (g) (T3)	RX (TRF1) (rad/sec ²)	RY (TRF2) (rad/sec ²)	RZ (TRF3) (rad/sec ²)
+7.4/-1.5	+/- 3.2	+/- 3.2	+/- 30.0	+/- 30.0	+/- 30.0

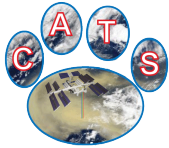
• Random Design Loads

FREQUENCY	LEVEL
20 Hz	0.002 g ² /Hz
20 – 70 Hz	+4.84 dB/oct
70 Hz	0.015 g ² /Hz
70 – 80 Hz	+3.86 dB/oct
80 – 400 Hz	0.0178 g ² /Hz
400 – 2000 Hz	-3.55 dB/oct
2000 Hz	0.00267 g ² /Hz
Composite	4.03 g root mean square (rms)
Duration	60 seconds



• Sine Design Loads

- LV Longitudinal: 6.0 G's
- LV Lateral: 3.0 G's

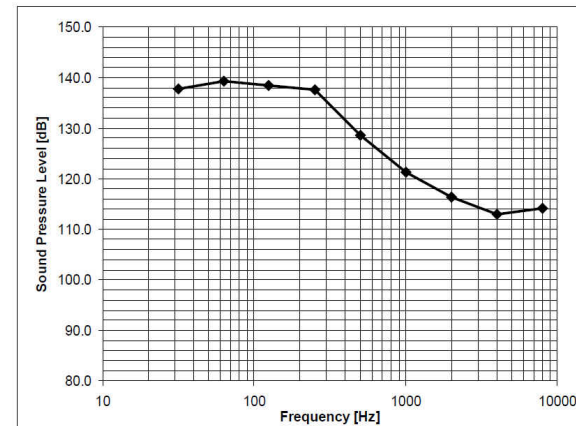


General Requirements (con't)

100

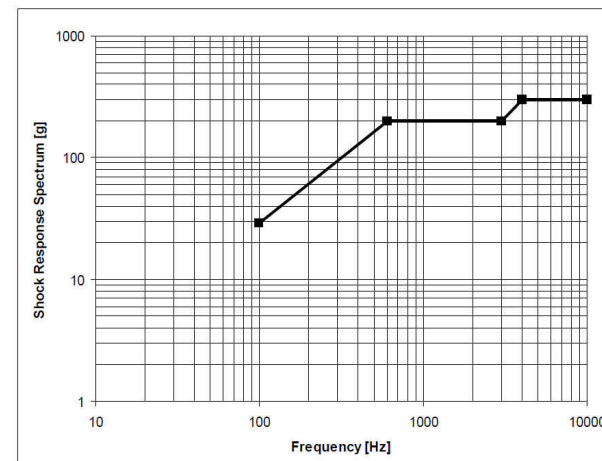
• Acoustic

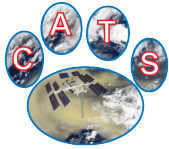
OCTAVE BAND CENTERED FREQUENCY [Hz]	SOUND PRESSURE LEVEL Ref. 2×10^{-5} N/m ² (20 microPascals) [dB]
31.5	137.7
63	139.2
125	138.4
250	137.5
500	128.5
1000	121.3
2000	116.3
4000	113
8000	114.2
Overall	144.4



• Shock Loads

FREQUENCY [Hz]	SHOCK RESPONSE SPECTRUM [g]
100	29
600	200
3000	200
4000	300
10000	300

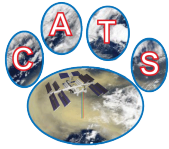




Fracture Control Requirements

101

- Fracture Control Plan Draft
 - CATS-ISS-MECH-PLAN-002
 - Fracture Plan Based Upon:
 - SSP 30558 Fracture Control requirements for Space Station
 - 731-0005-83: General fracture Control Plan for Payloads using the Space Transportation System (STS)
- Fracture Classifications:
 - Low Released Mass
 - Contained
 - Fail-Safe
 - Safe-Life
 - Low Risk
- Safe-Life Analysis and Tracking of all Safe-Life classified components



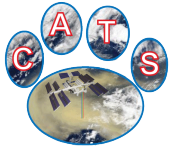
Structural Analysis Factors of Safety

102

- Taken from GEVS

Type	Static	Sine	Random/Acoustic
Metallic Yield-tested	1.25	1.25	1.6
Metallic Ultimate-tested	1.50	1.50	1.8
Metallic Yield-untested	2.00	2.00	-
Metallic Ultimate-untested	2.60	2.60	-
Buckling Ultimate	1.40	1.40	1.8
Composite Ultimate - final	1.50	1.50	1.9
Bonded Joints Ultimate - final	1.50	1.50	1.9
Composite Ultimate - pre-test	2.00	2.00	2.6
Bonded Joints Ultimate - pre-test	2.00	2.00	2.6
On Station Loads Yield - tested	1.10	1.10	-
On Station Loads Ultimate - tested	1.50	1.50	-

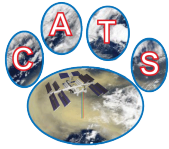
- NOTE: all FS used are 'tested' factors



Material Properties

103

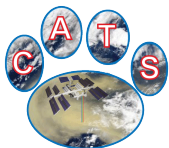
Alloy	ρ (kg/m ³)	E (Gpa)	ν	F _{tu} (Mpa)	F _{ty} (Mpa)	CTE (in/in/C)
6061-T6 Aluminum	2773	68.3	0.33	289	241	2.25E-05
Beryllium	1850	241	0.08	342	211	1.15E-05
Invar 30	8069	141	0.234	518	276	8.90E-06
6AL-4V Titanium	4429	110.3	0.31	896	813	8.60E-06
A-286 Steel (fasteners)	7944	200.6	0.31	1100	827	1.65E-05



General Analysis Approach

104

- Use of FEMAP/NASTRAN for all FEM work to date
- Use of spreadsheet-based hand calculations when appropriate
 - Assessment of yield/ultimate margins, etc.
 - Bolted joint sizing using extracted forces from FEM constraints and/or DOF springs
 - Tear-out assessment, bearing margins
 - Buckling assessment
- Final assessment of stresses, bolt forces, stiffness (frequency response), and deflections using plate and solid element models
- Analysis performed without most fillets, rounds, etc.
- Bolted joint analysis following NSTS 08307A (very conservative)
- Fracture Analysis of Safe-Life Components



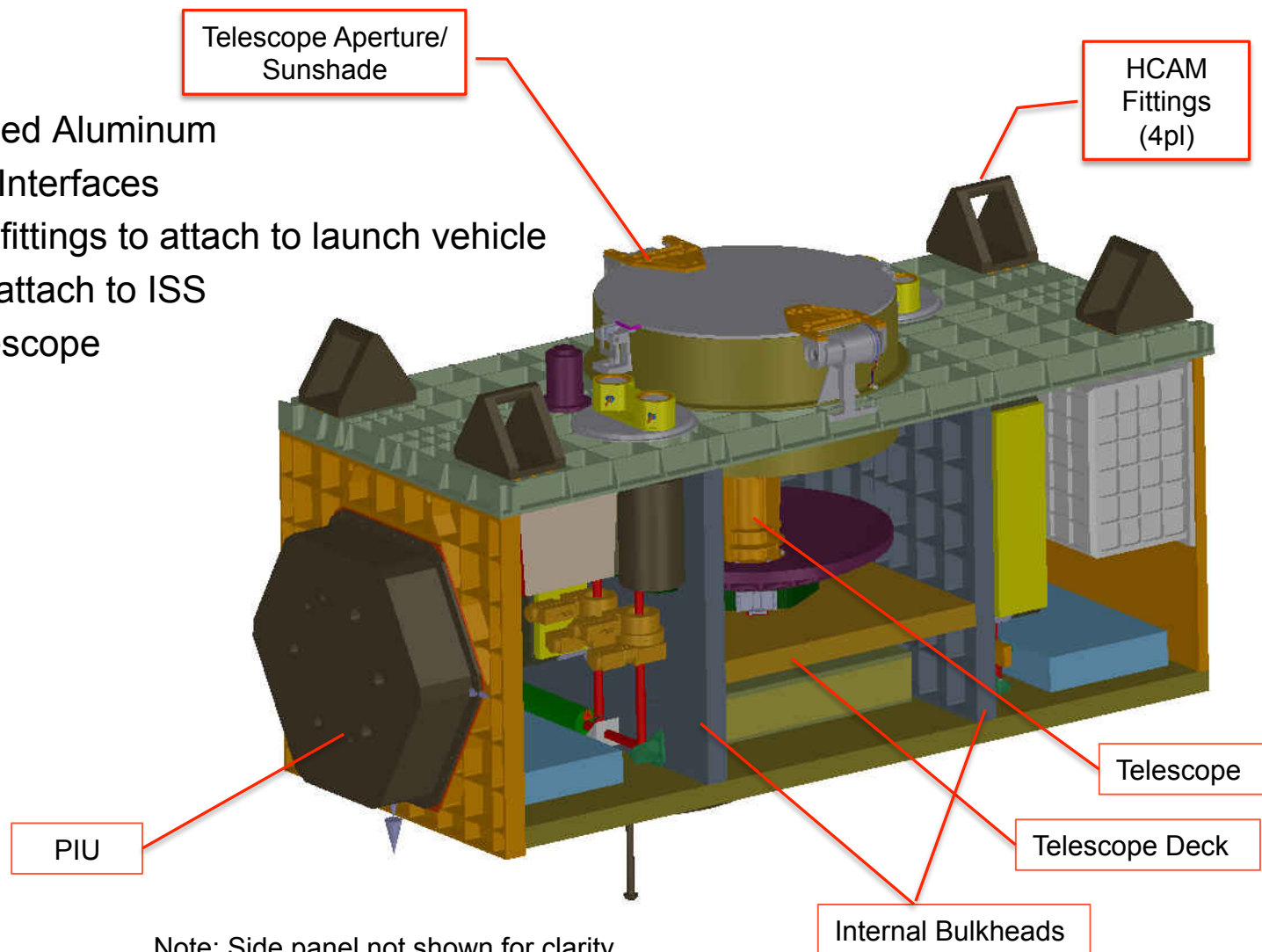
CATS Assembly Structural Description

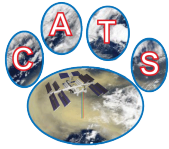
105

- All Panels

- Machined Aluminum
- Bolted Interfaces
- HCAM fittings to attach to launch vehicle
- PIU to attach to ISS

- Beryllium Telescope





CATS Mass Properties

106

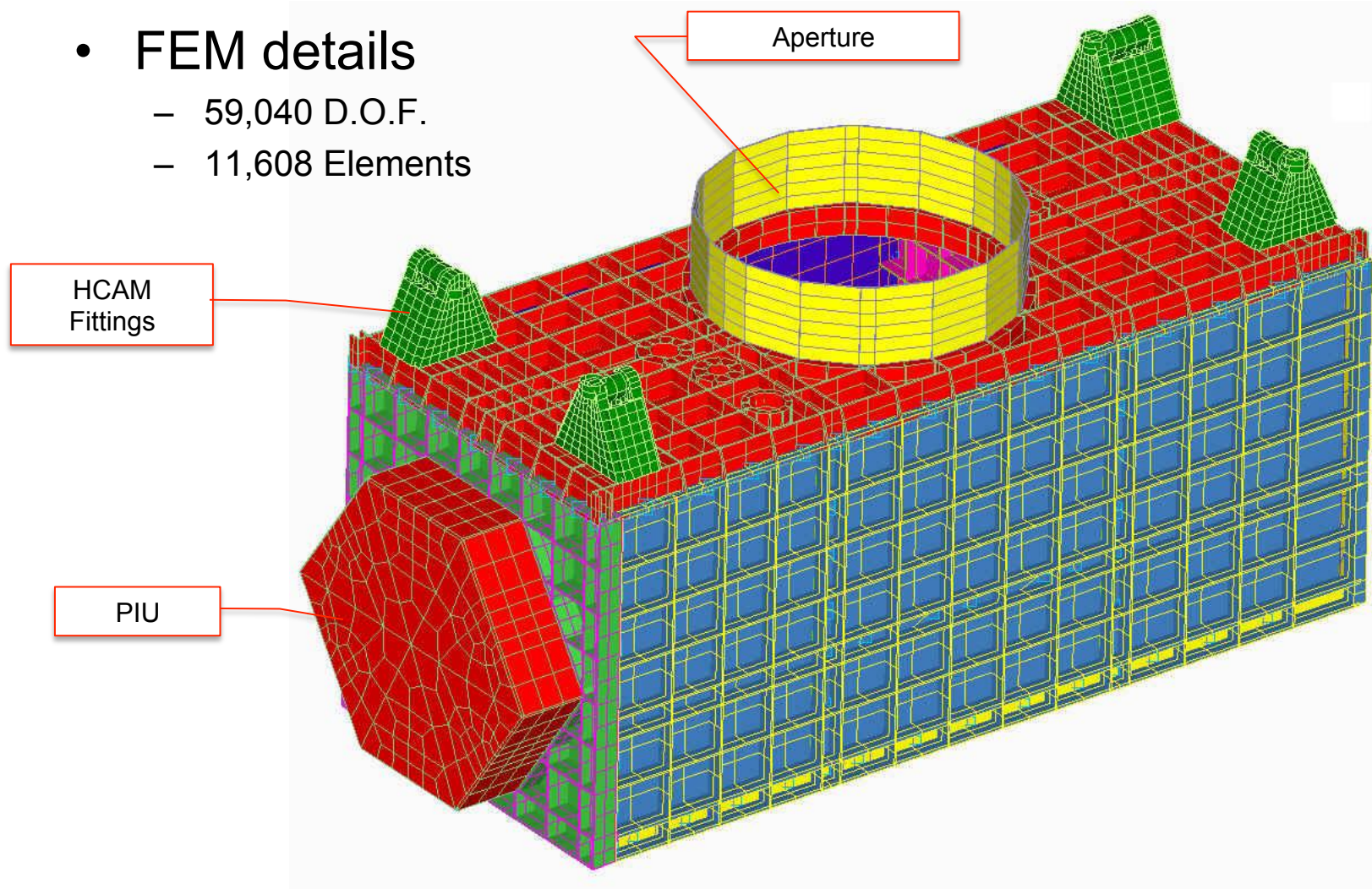
- Current 'stage' of analysis uses detailed panels with internal stiffeners, with components modeled as CONM2's attached with RBE3's
 - 59,040 D.O.F. with 11,608 elements (solid, shell, rigid, mass)
 - Mass correlated to Allocation;
 - Allocated mass = 500.0 kg
 - CBE = 452.8 kg
 - FEM mass
 - Panels (with smeared mass) 204.9 kg
 - HCAM Fittings 30.7 kg
 - Components 172.1 kg
 - PIU 32.4 kg
 - Grapple 12.7 kg
 - Total: 452.8 kg

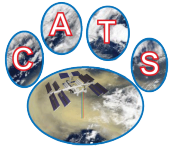


CATS Finite Element Model

107

- FEM details
 - 59,040 D.O.F.
 - 11,608 Elements





CATS Dynamic Modes on HCAM Fittings

108

- Results: Frequency Assessment
 - 4 HCAM mount constraint configuration
 - Modes with >5% MEW highlighted
 - Requirement: >50 Hz

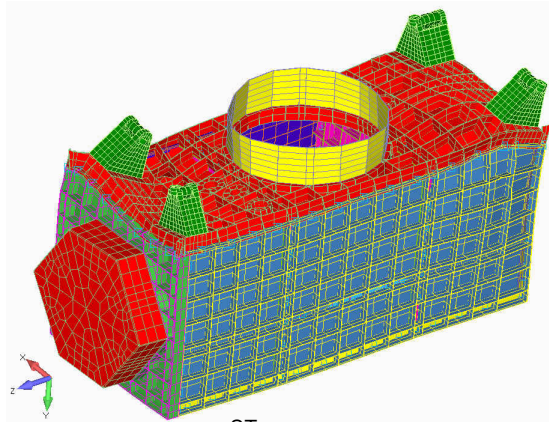
MODE	FREQUENCY	T1	T2	T3	R1	R2	R3
1	51.77	17%	0%	72%	7%	17%	14%
2	52.88	60%	0%	21%	3%	56%	59%
3	66.17	4%	2%	1%	1%	4%	3%
4	69.85	4%	2%	1%	1%	3%	3%
5	81.72	0%	6%	1%	5%	0%	0%
6	84.01	0%	12%	0%	7%	0%	0%
7	89.18	2%	0%	0%	0%	6%	0%
8	90.36	1%	0%	0%	1%	1%	0%
9	105.67	0%	21%	0%	16%	0%	0%
10	122.31	4%	2%	0%	3%	4%	6%
11	127.33	0%	25%	0%	23%	0%	0%
12	143.34	3%	1%	0%	1%	3%	9%
13	155.59	0%	0%	0%	1%	0%	0%
14	163.76	0%	0%	0%	2%	0%	0%
15	171.52	0%	0%	0%	0%	0%	0%
16	173.49	0%	0%	0%	0%	0%	0%
17	179.27	0%	0%	0%	0%	0%	0%
18	181.46	0%	0%	0%	0%	0%	0%
19	189.50	0%	0%	0%	1%	0%	0%
20	198.82	0%	0%	0%	0%	0%	0%



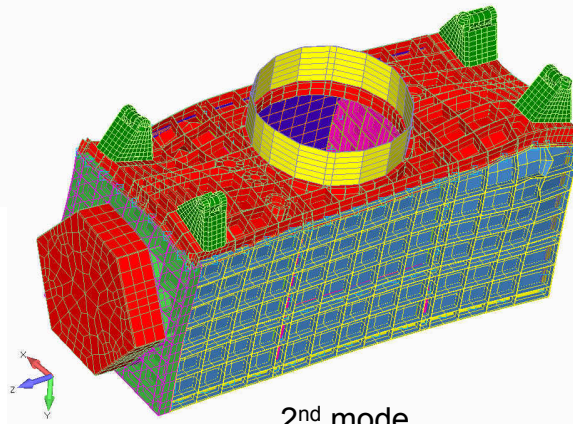
CATS Launch Dynamic Modes

109

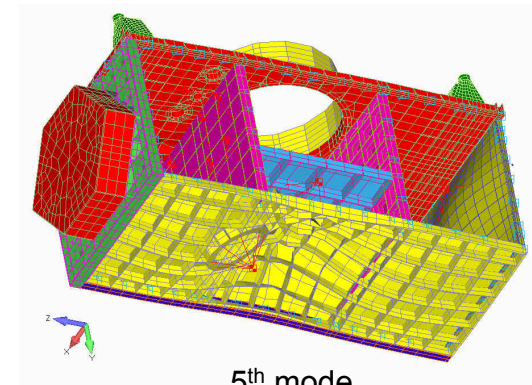
- Mode Shapes (for FEM constrained on HCAM fittings)



1ST mode
51.77 Hz.
Z-Mode

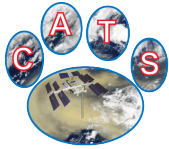


2nd mode
52.88 Hz
X-Mode



5th mode
84.01 Hz
Y-Mode

Note: Side Removed for clarity

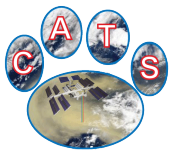


CATS Dynamic Modes on PIU

110

- Results: Frequency Assessment
 - PIU constraint configuration
 - Modes with >5% MEW highlighted
 - Requirement: >5 Hz

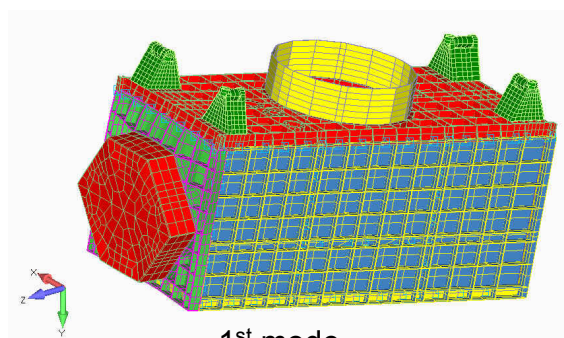
MODE	FREQUENCY	T1	T2	T3	R1	R2	R3
1	20.98	60%	5%	0%	2%	20%	23%
2	21.17	5%	58%	2%	20%	2%	2%
3	64.30	0%	0%	0%	0%	1%	4%
4	68.78	0%	0%	1%	1%	0%	1%
5	77.07	0%	0%	18%	1%	0%	7%
6	81.53	0%	2%	15%	0%	0%	26%
7	83.56	0%	2%	9%	1%	0%	8%
8	89.28	0%	0%	1%	0%	0%	0%
9	99.80	0%	3%	37%	0%	0%	0%



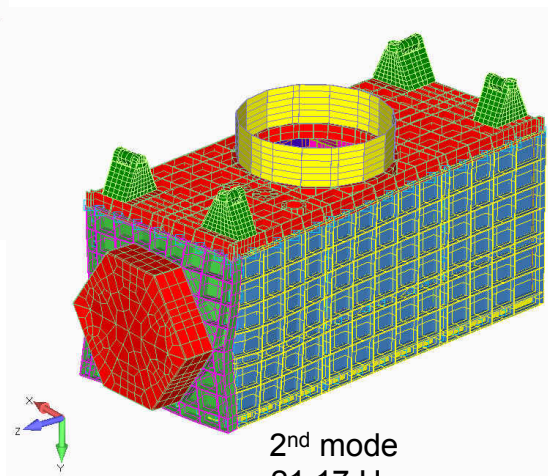
CATS Launch Dynamic Modes

111

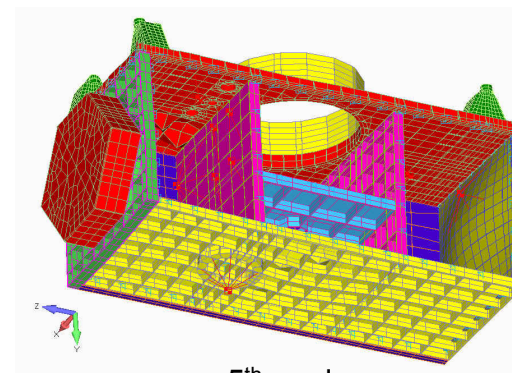
- Mode Shapes (for FEM constrained on PIU fitting)



1st mode
20.98 Hz.
Y-Bending

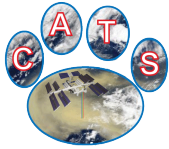


2nd mode
21.17 Hz
X-Bending



5th mode
77.07 Hz
Z-Axial

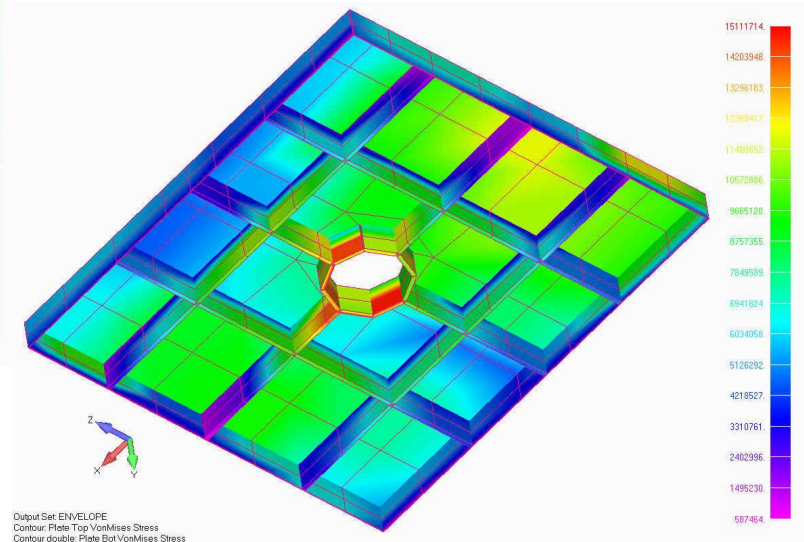
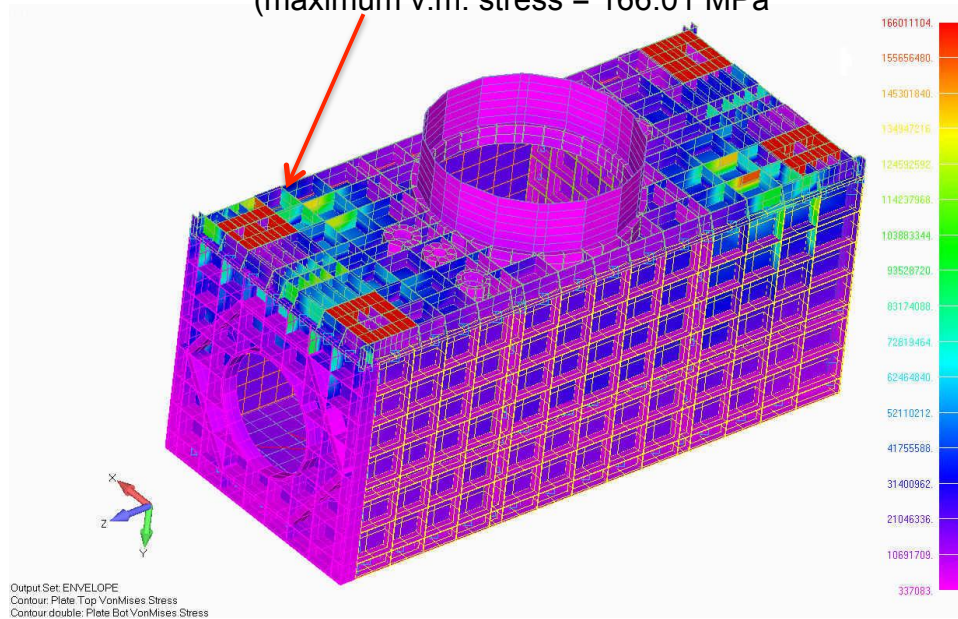
Note: Sides Removed for clarity



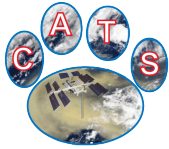
CATS Stress Analysis Results

112

CATS-ISS Housing Stresses
(maximum v.m. stress = 166.01 MPa)



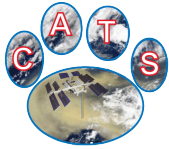
CATS-ISS telescope Deck Stresses
(maximum v.m. stress = 15.11 MPa)



CATS Assembly Analysis Results

113

- Launch Configuration
 - Dynamic Results
 - First CATS-ISS structural mode mounted on HCAM fittings is at 51.77 Hz.
 - Applied accelerations
 - Worse combination applied in each axis simultaneously
 - Maximum deflection is 2.8 mm
 - Maximum Structural von-mises stress is 166.01 Mpa
- On Orbit Configuration
 - Dynamic Results
 - First CATS-ISS structural mode mounted on PIU is at 20.98 Hz.
 - Applied accelerations
 - Worse combination applied in each axis simultaneously
 - Maximum deflection is 1.9 mm
 - Maximum Structural von-mises stress is 76.87 Mpa

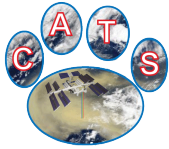


CATS Assembly Analysis Results (con't)

114

- Results: Assessment of Stress Margins:

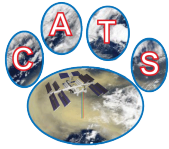
Component	Launch Stress (Pa)	On Orbit Stress (Pa)	Material	Ftu	Fty	M.S.(ult)	M.S.(yld)
Upper Deck (aperture)	166011104	17505298	6061 Al	2.89E+08	2.41E+08	0.16	0.16
Lower Deck (grapple)	39314100	19285082	6061 Al	2.89E+08	2.41E+08	3.90	3.90
Mid Deck (telescope mounting)	15111714	4630474	6061 Al	2.89E+08	2.41E+08	11.75	11.76
PIU Bulkhead	91520272	76870680	6061 Al	2.89E+08	2.41E+08	1.11	1.11
Laser 1 Bulkhead	22975476	5455128	6061 Al	2.89E+08	2.41E+08	7.39	7.39
Laser 2 Bulkhead	21884226	1844551	6061 Al	2.89E+08	2.41E+08	7.80	7.81
End Plate	64680900	1663867	6061 Al	2.89E+08	2.41E+08	1.98	1.98
Side Panels	118867696	25898874	6061 Al	2.89E+08	2.41E+08	0.62	0.62



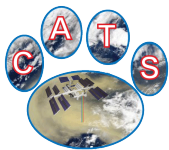
Structural Verification Testing

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- Qualification testing will be done at full instrument level
 - CATS-ISS with all components installed (no mass simulators) (proto-flight)
 - Sine
 - Sine Burst
 - Random
 - Acoustic Testing TBD
 - No Shock testing (no pyrotechnic devices)
- Preliminary Verification Plan Draft Complete
 - (CATS-ISS-MECH-PLAN-001)



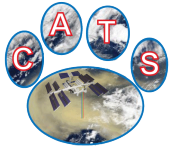
- Finalize CATS-ISS Structural Configuration
 - Optimize Structural Components
 - Weight Reduction
 - Update static analysis
 - Thermal loads and displacements
 - Base Drive analysis: sine/random
- Fracture
 - Classification
 - Safe-Life Analysis
- Qualification testing
 - Sine, sine burst, random
- Final Drawing Review
- GSE Requirements
- Documentation



Thermal

Paul Cleveland / ESI

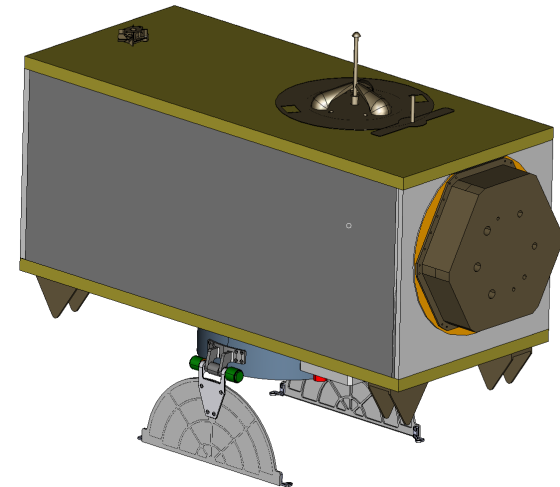
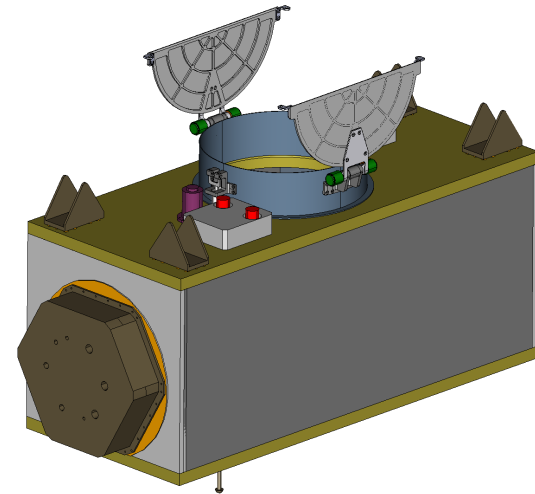
September 20, 2011

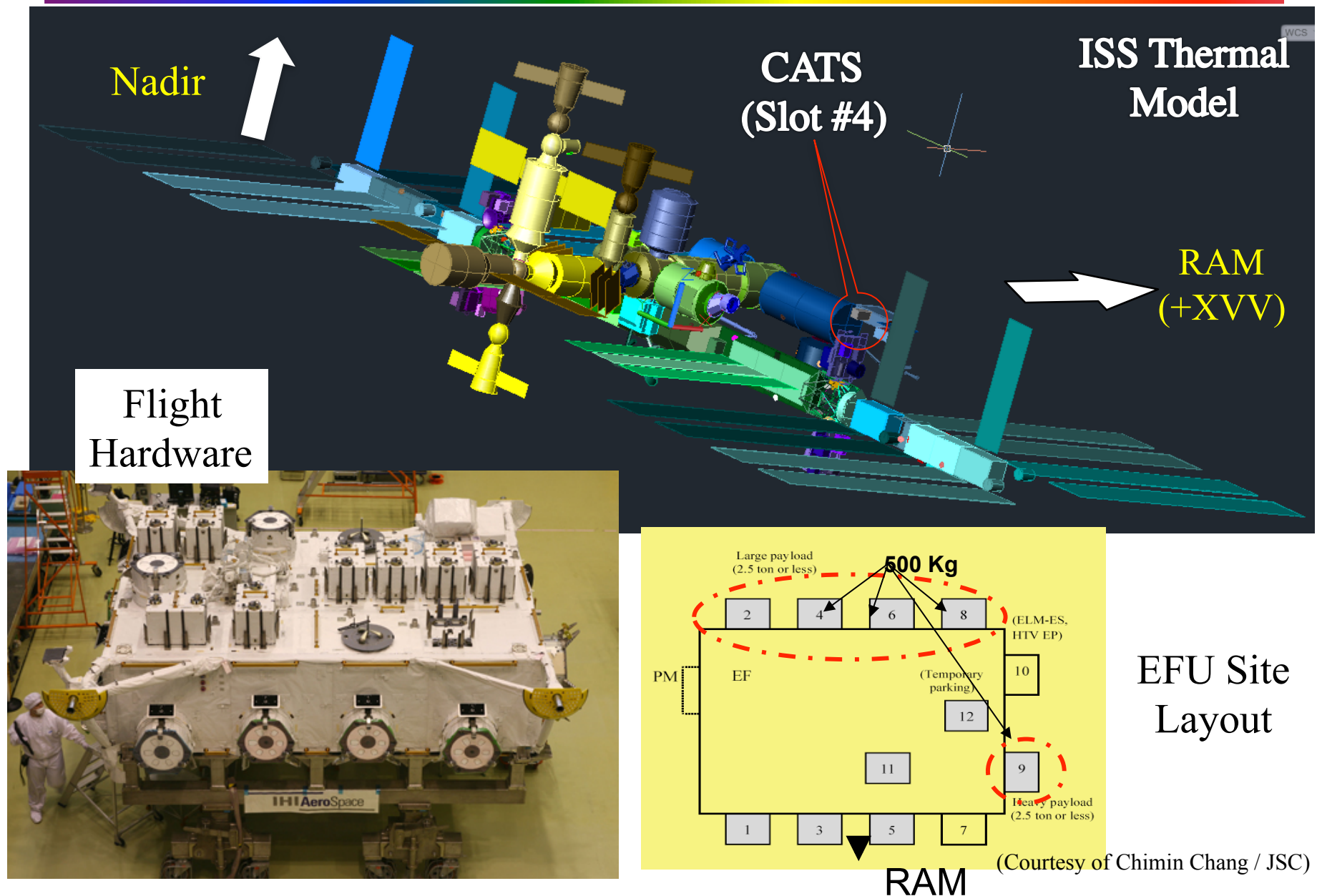


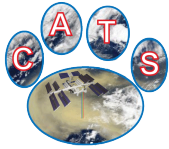
Agenda

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- **Background**
 - On-Orbit location
- **Key Thermal Requirements and Interfaces**
- **Thermal Design Approach**
 - Overall Configuration
 - Fluid Loop
 - Thermal Hardware
 - Heaters, Thermostats, Thermistors, MLI
- **Environments**
 - Launch
 - On-Orbit
- **Thermal Model & Analysis Cases**
- **Thermal System Performance Predictions**
 - Launch, Ascent, & Pre-Installation
 - On-orbit Average Hot and Cold Laser 1 Operation
- **Conclusion**
- **Future Work**







General Thermal Requirements

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- **Driving Design Documents**

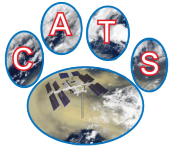
- NASDA-ESPC-2900A “*JEM Payload Accommodation Handbook, Vol. 3 Exposed facility/Payload Standard Interface Control Document*”
- JFX-2000073 “*The Exposed Facility Payload Thermal Math Model Requirements for JEM Element Integration Thermal Analysis*”
- NASDA-ESPC-2857 “*HTV Cargo Standard Interface Requirements Document*”
- NASDA-ESPC-3122 “*Payload Interface Unit Product Specification*”
- SSP30573, “*Fluid Procurement and Use Control Specification*”
- Safety Requirements identified at the Phase 1 Safety Review and Hazard Reports



Key Thermal Requirements & Interfaces

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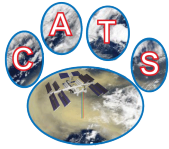
Subassembly	Part	Survival	Operational Temp
Telescope	Primary	-40 to +50 C	-10 to +45 C
	secondary	-40 to +50 C	-10 to +45 C
	metering structure	-40 to +50 C	-10 to +45 C
	interface plate	-40 to +50 C	-10 to +45 C
	secondary mirror baffle	-40 to +50 C	-10 to +45 C
Transmitter MFOV path	Laser 1 Diodes	0 to +50	+24 to +26
	LOM Coldplate	-10 to +50	+10 to +40
	LEM Coldplate	-10 to +50	+10 to +40
	laser 1 beam expander	-30 to +50	+10 to +40
	power beam splitter	-30 to +50	+10 to +40
	fold mirror	-30 to +50	+10 to +40
	Left View rotation stage 1	-10 to +50	+10 to +40
	Left View rotation stage 2	-10 to +50	+10 to +40
	Right View rotation stage 1	-10 to +50	+10 to +40
	Right View rotation stage 2	-10 to +50	+10 to +40
Transmitter CPL and HSRL Path	Laser 2 Diodes	0 to +50	+24 to +26
	LOM Coldplate	-10 to +50	+10 to +40
	LEM Coldplate	-10 to +50	+10 to +40
	Laser Path Select Stage	-10 to +50	+10 to +40
	HSRL Beam Expander	-30 to +50	+10 to +40
	HSRL Fold Mirror	-30 to +50	+10 to +40
	HSRL Rotation Stage 1	-10 to +50	+10 to +40
	HSRL Rotation Stage 2	-10 to +50	+10 to +40
	HSRL Rotation Stage 3	-10 to +50	+10 to +40
	THG	-20 to + 60	0 to +45
	CPL Beam Expander	-30 to +50	+10 to +40
	CPL Fold Mirror	-30 to +50	+10 to +40
	CPL Rotation Stage 1	-10 to + 40	+10 to +40
	CPL Rotation Stage 2	-10 to + 40	+10 to +40
Data System	DSRM	-65 to +150	-40 to +70
	PDA	-65 to +150	-40 to +90



Key Thermal Requirements & Interfaces

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Port View Detector Box	(Nominally operated with Starboard View Detector Box)		
	SPCM (532 II #1)	-20 to +70	+5 to +45
	SPCM (532 II #2)	-20 to +70	+5 to +45
	SPCM (532 \perp #1)	-20 to +70	+5 to +45
	SPCM (532 \perp #2)	-20 to +70	+5 to +45
	SPCM (1064 II)	-20 to +70	+5 to +45
	SPCM (1064 \perp)	-20 to +70	+5 to +45
Door Assembly	pressure sensor	-20 to +70	-10 to +60
	door motor assembly	-55 to +75	-45 to +65
Housing	door interlock	-20 to +70	-10 to +60
	H-Fixture	-101 to +121	-101 to +121
	PIU	-45 to +79	-45 to +65
	FRGF Grapple	-156 to +121	-76 to +68
	HCAM-P	-65 to +150	-50 to +70
	HCSM-P	-65 to +150	-50 to +70



Key Thermal Requirements & Interfaces

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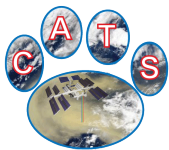
- **NASDA-ESPC-2900A JEM Payload Accommodation Handbook (Vol. 3 Exposed facility/Payload Standard Interface Control Document)**

- 3.5.3.2 Passive Thermal Control System (PTCS) interface
 - Survival Power: (3.5.1.1) 120[W] (@120V) x 1 channel/payload.
- 3.5.3.2.1 Heat Radiation Interface
 - MLI required with White Beta Cloth outer layer

Table 3.5.3-1 Therm-Optical Characteristics of EF Experiment Payload Outer Surfaces

Item	Characteristic value
MLI effective thermal emissivity	$\varepsilon_{\text{eff}} \leq 0.04$
MLI thermo-optical characteristics	$\alpha = 0.31 - 0.6$ $\varepsilon = 0.85 - 0.96$

- TRASYS / SINDA model must be supplied to JAXA for integrated analysis
- 3.5.3.2.2 Thermal Conduction Interface
 - Interface surface temperature between EFU and PIU -45 to +65C
 - Temperature difference of EFU and PIU interface at mating <80C



Key Thermal Requirements & Interfaces

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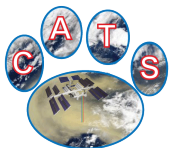
• NASDA-ESPC-2900A JEM Payload Accommodation Handbook (Vol. 3 Exposed facility/Payload Standard Interface Control Document)

- 3.5.3.3 Active Thermal Control System (ATCS) interface
 - Coolant flow stopped to non-operating payloads. (Cannot be a source of heat)
- 3.5.3.3.1 Coolant
 - Coolant Type: Perfluorocarbon (Fluorinert FC-72) (a 3M product)
- 3.5.3.3.2 Coolant Supply Characteristics (I/F temp, flow rate, MDP)

Table 3.5.3-2 ATCS Fluid Interface

Interface parameter	Coolant Temperature		Max. allowable heat waste from PL [kW]	Provided Coolant flow rate* ² [kg/h/kW]	Coolant pressure under nominal operation [MPa] ([kgf/cm ² A])	Coolant maximum design pressure in system * ³ [MPa] ([kgf/cm ² A])
	Supplied Coolant Temperature to PL [°C]	Returned Coolant Temperature from PL [°C]				
	16 - 24 * ¹	16 - 50 * ¹	3.0 (Not higher than 6.0 [kw] for EEU #1, #2)	155 ^{+18%} _{-0%}	No higher than 0.78 (8.0)	1.57 (16.0)

- *1. • Excluding the time until the flow rate, temperature, etc. are stabilized after the operational conditions of the ATCS fluid loop are changed, such as startup time or configuration change.
- Depending on the operation and configuration (the number of Payloads, attached location, heat waste, etc.), it may happen to deviate the above range. Further information should be confirmed with Element Integrator for each Payload.
- *2. It indicates the flow rate of coolant supplied by EF to PL for a unit heat volume (including the influence of the Payload attaching position). Note that the time until the flow rate is stabilized after the operational conditions of the ATCS fluid loop are changed, such as startup time or configuration change is excluded.
- *3. This condition can occur between EFU back-pressure valve and a quick-disconnector after two failures.
- The value 1.57 [MPa] consists of "Maximum pressure 1.18 [MPa] " and "Back-pressure valve relief pressure 0.39 [MPa]."



Key Thermal Requirements & Interfaces

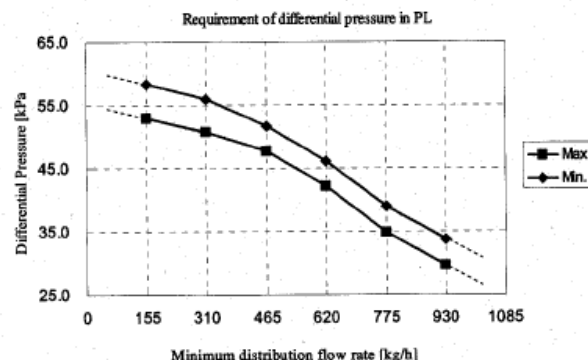
126

- NASDA-ESPC-2900A JEM Payload Accommodation Handbook (Vol. 3 Exposed facility/ Payload Standard Interface Control Document)

- 3.5.3.3.3 Payload ATCS Design Characteristics

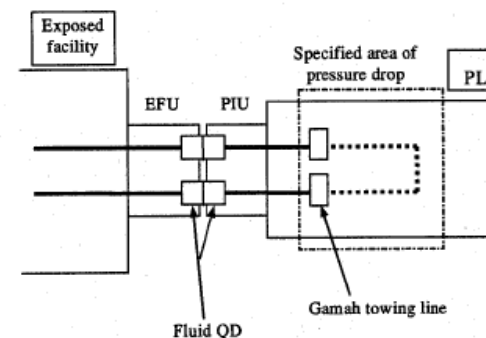
- (1) Pressure Drop
 - See Table 3.5.3-3
 - No flow control valves allowed.

Table 3.5.3-3 Fluid Differential Pressure Required in the EF Experiment Payload



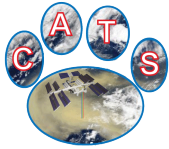
Specified differential pressure in payload

Amount of waste heat [kW]	Minimum distribution of flow rate [kg/h]	Differential Pressure [kPa] ((kgf/cm ² D))	
		Minimum	Maximum
1	155	52.9 (0.540)	58.4 (0.595)
2	310	50.7 (0.517)	55.9 (0.570)
3	465	47.7 (0.486)	51.7 (0.528)
4	620	42.1 (0.429)	46.1 (0.470)
5	775	34.9 (0.356)	39.0 (0.398)
6	930	29.6 (0.301)	33.8 (0.344)



Note that the pressure loss in the PIU is not included.

The minimum distribution of the flow rate of coolant to each payload for the amount of waste heat is indicated in the table. The payload shall be designed so that the pressure drops when the amount of coolant shown in the table flows is within the values specified above.



Key Thermal Requirements & Interfaces

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- **NASDA-ESPC-2900A JEM Payload Accommodation Handbook (Vol. 3 Exposed facility/Payload Standard Interface Control Document)**

- 3.5.3.3.3 Payload ATCS Design Characteristics (continued)

- (2) Cleanliness
 - See Table 3.5.3-4
 - Heat exchanger or cold plates required
 - Filter (< 40 micro-meter) required in outlet loop

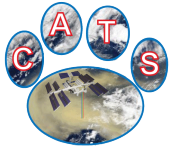
Table 3.5.3-4 Cleanliness Requirements for EF Experiment Payload Fluid Systems

Particle size [μm]	Maximum allowable number per 100 [ml] test fluid * ¹
0 - 5	Unlimited
6 - 10	3600
11 - 25	1050
26 - 50	210
51 - 100	20* ²
101 - 250	2
251 or over	Not allowed

*1. Fiber is included.

Note that “fiber” means a non-metallic particle whose length is 100 [μm] or longer and whose length/diameter ratio is 10/1 or less.

*2. Note that no metallic particle whose length is 51 [μm] or longer is allowed.



Key Thermal Requirements & Interfaces

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- **NASDA-ESPC-2900A JEM Payload Accommodation Handbook (Vol. 3 Exposed facility/Payload Standard Interface Control Document)**

- 3.5.3.3.3 Payload ATCS Design Characteristics (continued)

- (3) Coolant Compatibility: Plumbing system shall be compliant with FC-72
- (4) Fluid Pressure During Payload Berthing Operation: Fluid pressure ≤ 785 kPa
- (5) Leakage: See Table 3.5.3-5
- (6) Coolant capacity of the fluid system: < 2.0 L (including volume in PIU)
- (8) Failure Tolerance Requirement:
 - When flow stops, CATS can turn OFF
 - CATS shall have an Accumulator or volume compensator
 - CATS shall “comply to any two-fault tolerant for MDP (16.0 kgf/cm²A) exceedance”
- (9) Coolant Filling: CATS shall be filled with coolant before launch at room temp.
- (10) Absorption of Coolant: CATS shall not absorb coolant from EF system when pressure is 471 kPa or less and at any thermal environment

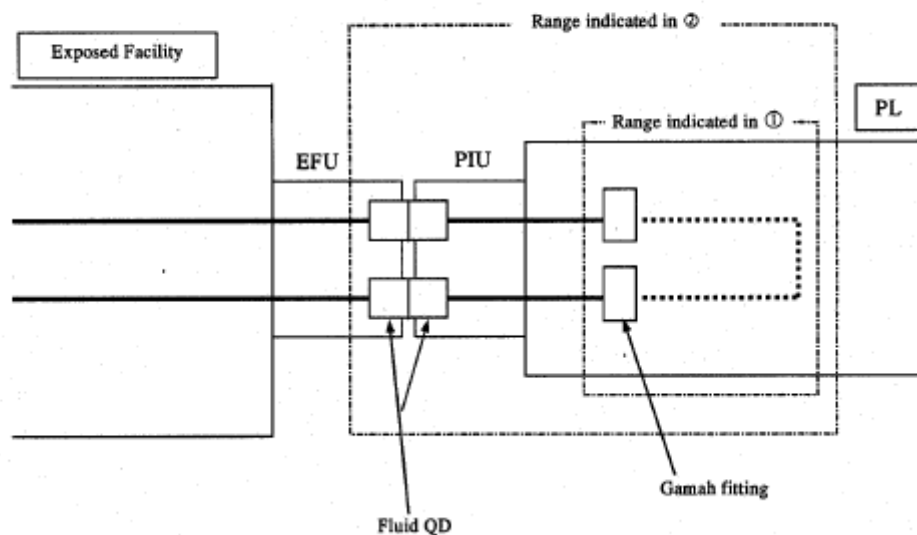


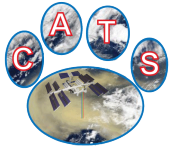
Key Thermal Requirements & Interfaces

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Table 3.5.3-5 Allowable leak for EF Experiment Payloads

	Allowable leak	Remarks
① Fluid QD not included	$1.01 \times 10^{-6} [\text{Pa} \cdot \text{m}^3/\text{s}]$ @ 1.18[MPa] (1×10^{-5} [sccsGHe : @ 12kgf/cm ² A])	Including the leak in the Gamah towing line part
② Fluid QD included (Reference data)	$3.04 \times 10^{-6} [\text{Pa} \cdot \text{m}^3/\text{s}]$ @ 1.18[MPa] (3×10^{-5} [sccsGHe : @ 12kgf/cm ² A])	−45 to +16 [°C]
	$7.09 \times 10^{-6} [\text{Pa} \cdot \text{m}^3/\text{s}]$ @ 1.18[MPa] (7×10^{-5} [sccsGHe : @ 12kgf/cm ² A])	+16 to +65 [°C]
	$2.13 \times 10^{-5} [\text{Pa} \cdot \text{m}^3/\text{s}]$ @ 1.18[MPa] (2.1×10^{-4} [sccsGHe : @ 12kgf/cm ² A])	+65 to +79 [°C]

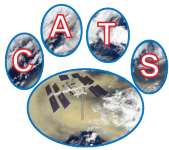




Thermal Design Approach

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- **Entire main structure and aperture door covered with Multi-Layer Insulation (MLI) including interior surface of telescope shroud**
 - Effective emittance = 0.03
 - White Beta Cloth outer layer
- **Entire metering structure covered with MLI**
- **All primary electronics cooled via JAXA supplied fluid.**
 - Fluid: 3M Fluorinert™ FC-72 Electronic Liquid
 - Boxes: Laser 1 LEM and LOM, Laser 2 LEM and LOM, HSRL, three Detector Boxes, Main Electronics Box, and Main Power Supply
 - Cold plates: Mounted to boxes
- **Fluid Loop: Single / series configuration**
- **Laser 1 and 2 LOM's and the Main Power Supply are also mounted to their respective benches via titanium flexures.**
 - Flexures provide thermal isolation to minimize optical bench operational gradients.



Thermal Design Approach (cont'd)

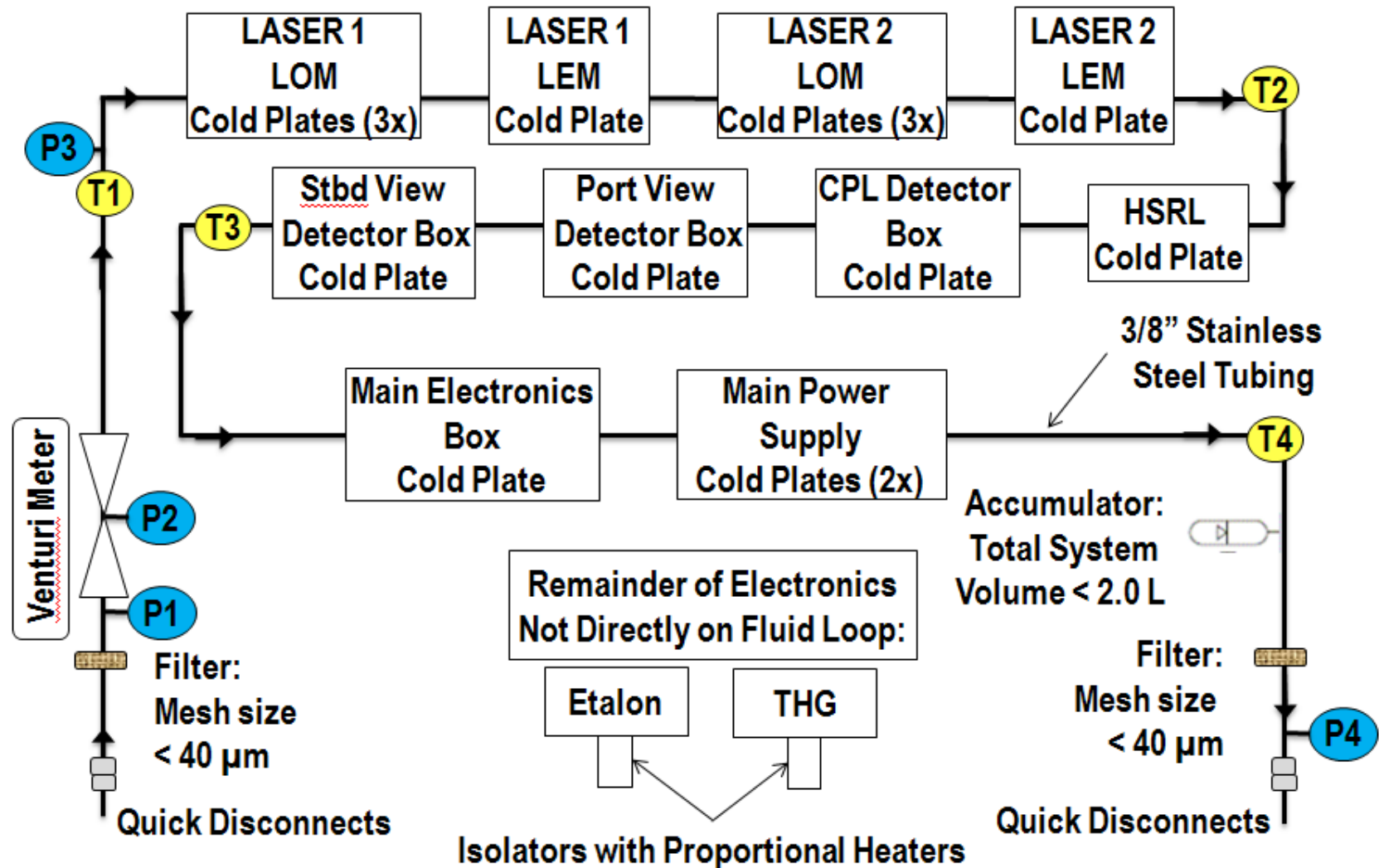
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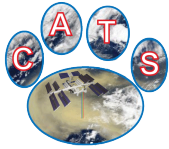
- **Other electronics hard mounted to their respective panels**
 - Some heat goes into the panels.
- **Interior surfaces are high emittance : black paint, anodize, etc.**
- **Survival heaters:**
 - One circuit for main structure – create a warm box environment
 - One circuit for PIU
 - Used to protect hardware during launch and transport
 - Used to protect hardware during on-orbit anomalies
- **All externally mounted hardware (except H-Fixture) is thermally isolated from box structure via G-10 isolators. Includes:**
 - FRGF Grapple Fixture, PIU Assembly (TBR), HCAM Mounts, HCSM-P
- **Laser diodes utilize Thermo Electric Coolers (TEC's) to provide temperature and stability control**
- **Etalon and THG utilize proportionally controlled heaters to provide temperature and stability control**



Fluid Loop Schematic (Single Series Loop)

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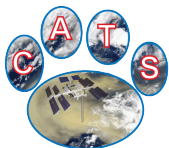




Heaters & Thermostats

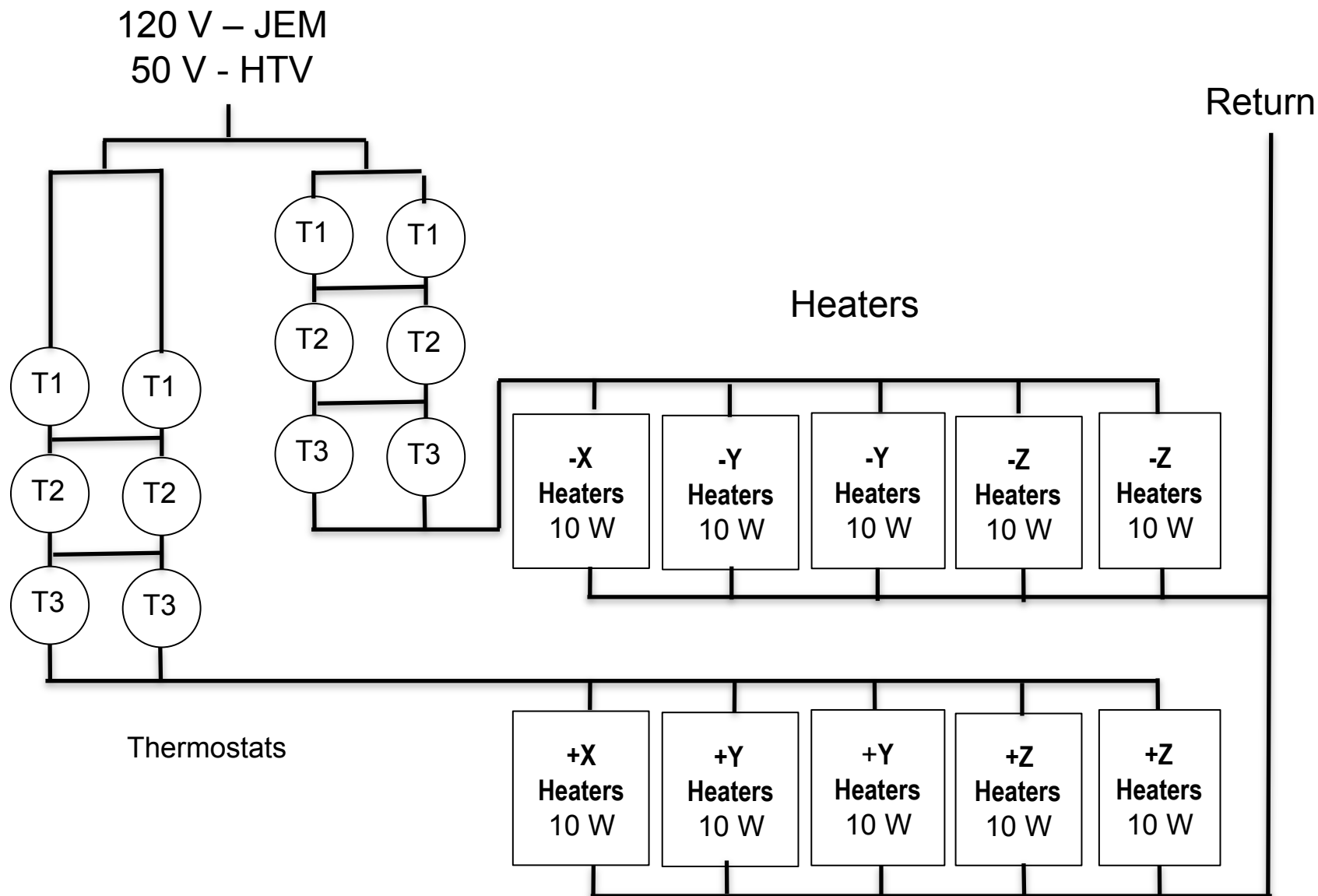
133

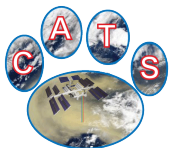
- **Survival Heater Power needed is 100 W maximum (50 W during launch)**
 - Based on worst case cold analysis presented below
- **Heaters selected**
 - Thermofoil Heater Specification: GSFC S-311-P-079
 - Vendors per Qualified Parts List Directory: GSFC-311-QPLD-015
 - MINCO Products Manufac. to GSFC Spec.
 - TAYCO ENGINEERING, INC Tayco spec. TPS-5010
- **Thermostats selected**
 - HTV Nominal set point +10°C (283 K)
 - JEM Nominal set point +15°C (288 K)
 - Thermostat Specification: GSFC S-311-641
 - Vendors per Qualified Parts List Directory: GSFC-311-QPLD-015
 - SENSATA TECHNOLOGOES INC M2 Series
 - Honeywell DSES Redmond, WA 700 Series
 - Thermostats rated at 5 amps, derated to 2.5 amps
- **Thermostat configuration makes system two fault tolerate**



Survival Heater Circuit Schematic

134





Survival Heater Power Available

135

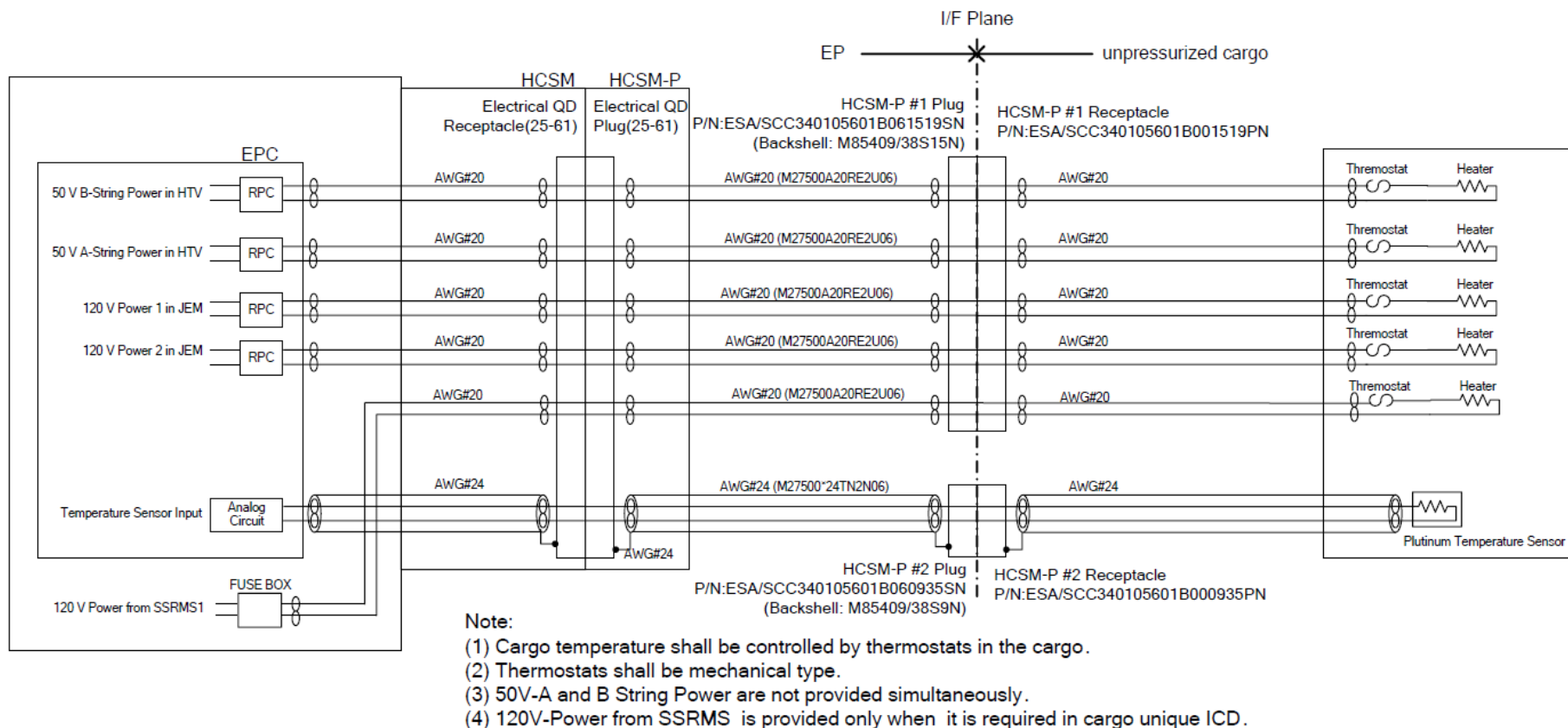
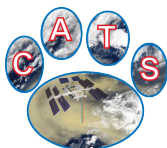


Fig. 3.3.2.2-1 Electrical I/F Schematic for HCSM/HCSM-P



Thermistors

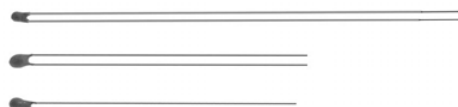
136

M, C, T

Vishay Dale



NTC Thermistors, Coated



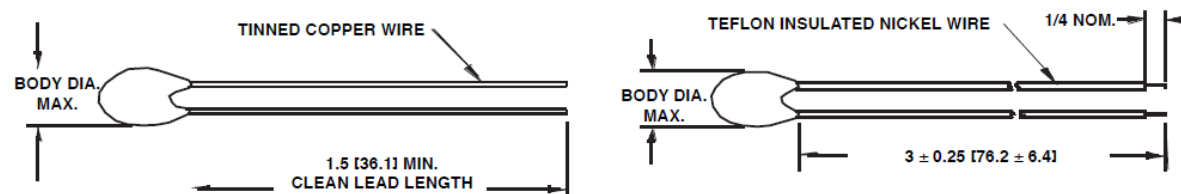
FEATURES

- Small size - conformally coated.
- Wide resistance range.
- Available in 11 different R-T curves.

DESCRIPTION

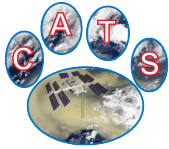
Models M, C, and T are conformally coated, leaded thermistors for standard PC board mounting or assembly in probes. The coating is baked-on phenolic for durability and long-term stability. Models M and C have tinned solid copper leads. Model T has solid nickel wires with Teflon® insulation to provide isolation when assembled in metal probes or housings.

DIMENSIONS in inches [millimeters]



LD DIAMETER	WIRE SIZE
Type M	AWG 30: 0.0100 [0.254]
Type C	AWG 28: 0.0126 [0.320]
Type T	AWG 30: 0.0100 [0.254]

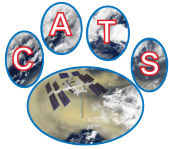
STANDARD ELECTRICAL SPECIFICATIONS FOR CURVE TRACKING THERMISTORS																
TEMP. RANGE		0 °C to + 70 °C			- 20 °C to + 50 °C			0 °C to + 100 °C			25 °C to + 90 °C			0 °C to + 50 °C		
TOLERANCE		± 1 °C	± 0.5 °C	± 0.2 °C	± 1 °C	± 0.5 °C	± 0.2 °C	± 1 °C	± 0.5 °C	± 0.2 °C	± 1 °C	± 0.5 °C	± 0.2 °C	± 1 °C	± 0.5 °C	± 0.2 °C
PART NO. SUFFIX		- A3	- B3	- C3	- A2	- B2	- C2	- A4	- B4	- C4	- A5	- B5	- C5	- A8	- B8	- C8
C	1	X	X	X	X	X	X	X	X	N/A	X	X	X	X	X	X
U	2	X	X	X	X	X	X	X	X	N/A	X	X	X	X	X	X
R	4	X	X	X	X	X	X	X	X	N/A	X	X	X	X	X	X
V	8	X	X	X	X	X	X	X	X	N/A	X	X	X	X	X	X
E	9	X	X	X	X	X	X	X	X	N/A	X	X	X	X	X	X



Multi-Layer Insulation (MLI)

137

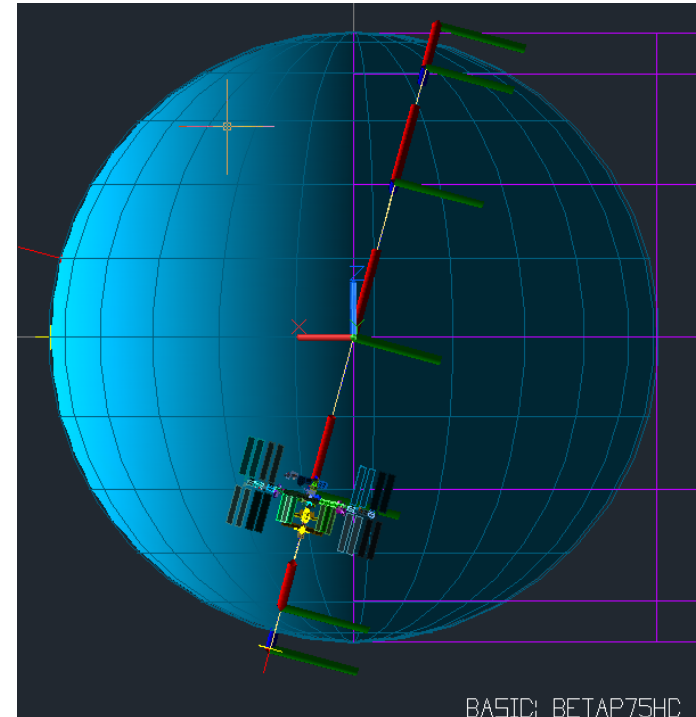
- **Use standard Goddard blanket:**
 - 18 layers of 1/4 mil Mylar, Vapor Deposited Aluminum (VDA) two sides
 - Alternating B-2A Dacron mesh separators,
 - All sandwiched between a 3 mil thick and a 1 mil thick Kapton film sheet aluminized on one face.
 - The aluminized side of both Kapton layers face the inner layers
 - White Beta Cloth outer layer
- **Vented per GSFC standards – typically edge venting with filters**
- **MLI grounding per NASA/GSFC 549-WI-8071.0.7**



Environments - On Orbit Hot Case

139

- Beta Angle Range: -75° to $+75^{\circ}$
- Hot Case Beta Angle = $+75^{\circ}$ & $+30^{\circ}$
- EOL Properties
- Altitude: 226.8 nm (420 km)
- ISS Flying +XVV = +X Velocity Vector
- Hot Case Environmental Parameters
 - Solar 450 BTU/hr/ft²
 - Albedo 0.35
 - Planetshine 73.1 BTU/hr/ft²
- Conducted environmental study to determine worst cold case orbit.
- Analyzed a 32" x 32" x 73" Black Brick
 - Single Node
 - Solar Absorptance = 1.0
 - Hemispherical Emittance = 1.0



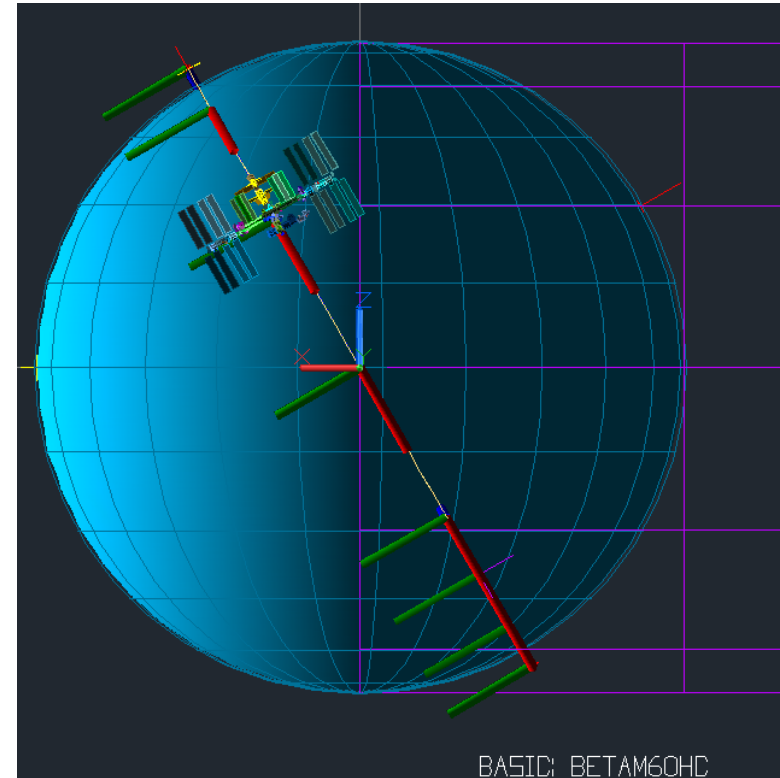
Orbit Average		
Beta Angle	Temperature	
-75	33.9 F	1.1 C
75	68.6 F	20.3 C
60	60.0 F	15.6 C
45	62.5 F	17.0 C
30	69.1 F	20.6 C
15	58.4 F	14.7 C
0	45.1 F	7.3 C



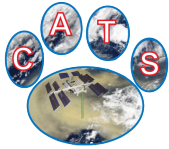
Environments - On Orbit Cold Case

140

- **Beta Angle Range: -75° to $+75^{\circ}$**
- **Beta Angle = -60°**
- **BOL Properties**
- **Altitude: 226.8 nm (420 km)**
- **ISS Flying +XVV = +X Velocity Vector**
- **Cold Case Environmental Parameters**
 - Solar 408 BTU/hr/ft²
 - Albedo 0.25
 - Planetshine 66 BTU/hr/ft²
- **Conducted environmental study to determine worst cold case orbit.**
- **Analyzed a 32" x 32" x 73" Black Brick**
 - Single Node
 - Solar Absorptance = 1.0
 - Hemispherical Emittance = 1.0
- **Beta Cloth cube @ Beta Angle = -60**
 - -52.9F = -51C
 - Used in the cold case analysis



Beta Angle Orbit Average Temperature		
75	52.3 F	11.3 C
-75	17.9 F	-7.9 C
-60	-12.6 F	-24.8 C
-45	-9.6 F	-23.1 C
-30	5.7 F	-14.6 C
0	22.6 F	-5.2 C



Thermal Model & Analysis Cases

141

- Geometric Math Model - Thermal Desktop version 5.3, AutoCAD 2011
- Thermal Math Model – SINDA/FLUINT version 5.3

- **Analyses Cases:**

- **Transport (Worst Case):**

- Environment Sink Temp = -266°C
 - MLI effective emittance = 0.05
 - Survival Power = varied

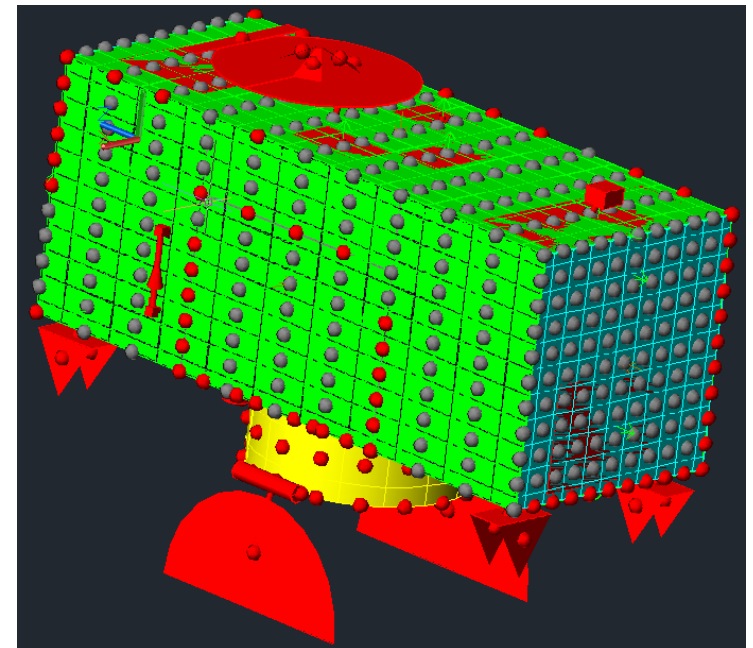
- **Hot Case:**

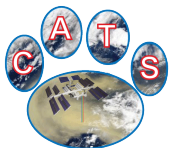
- Beta angle 30°
 - Equivalent Sink (Black) = $+21^{\circ}\text{C}$
 - Laser 1 operation: 770 W
 - Fluid mass flow rate: 155 kg/hr

- **Cold Case:**

- Beta angle -60°
 - Equivalent Sink (White) = -51°C
 - Laser 1 operation: 770 W
 - Fluid mass flow rate: 155 kg/hr

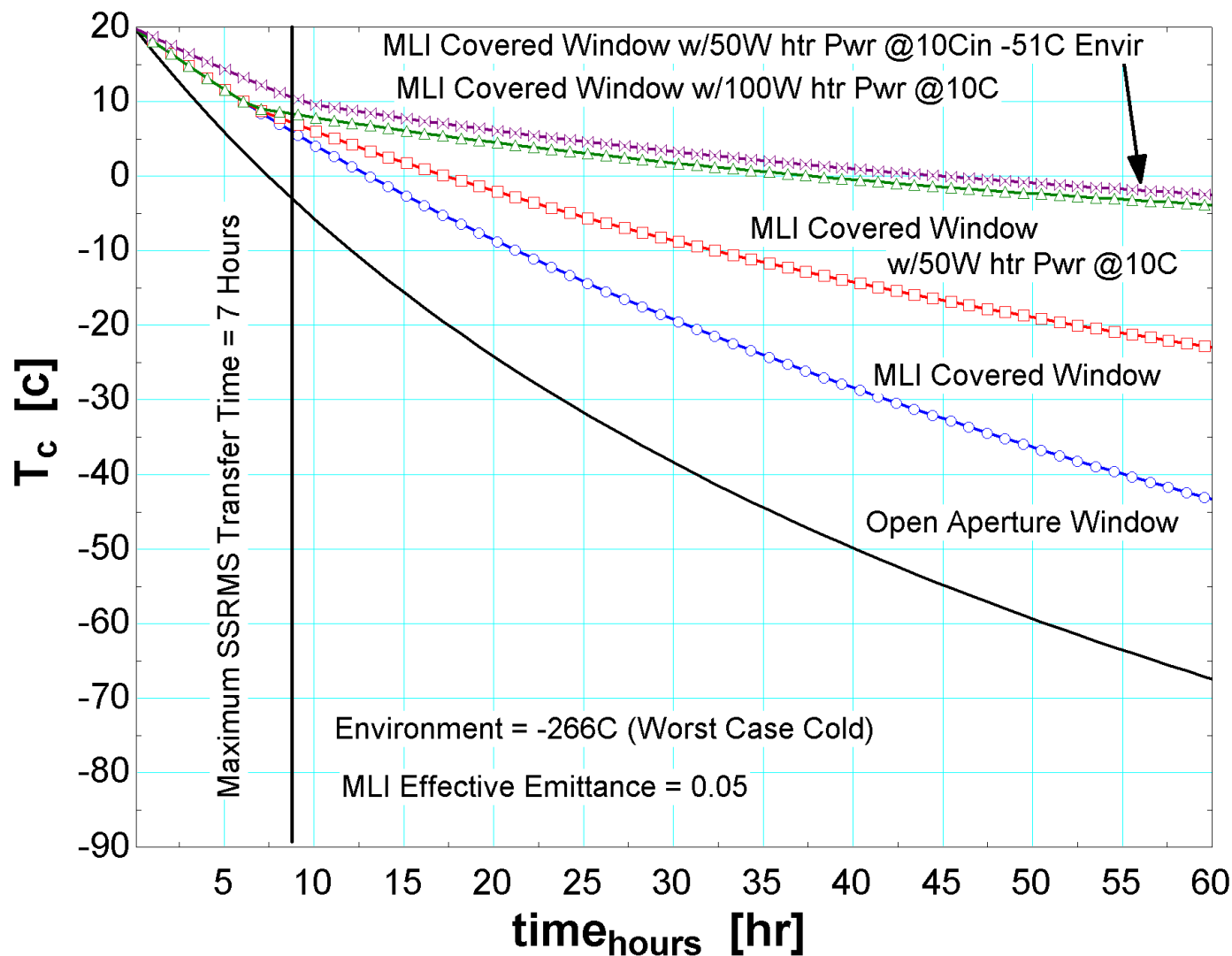
```
1216 objects selected
985 TD/RC Nodes
17 User Nodes
2 boundary
813 MLI (non graphical)
48 planar elements
49 surfaces
30 fdsolids
68 conductors
8 heat loads
11 contactors
```





Survival Heater Temperature Predictions (Preliminary - Worst Case Cold)

142





Assumptions – Laser 1 Operational Mode

143

- **Single Loop configuration**
- **Laser 1 operational mode (770 W total)**
 - Port View Detector Box 15 W
 - Starboard View Detector Box 15 W
 - Data System 90 W
 - Laser 1 LOM 300 W
 - Laser 1 LEM 100 W
 - Main Power Supply 250 W
- **FC-72 fluid temperature:**
 - Hot Case +24 C
 - Cold Case +16 C
- **Telescope door is open**
- **Environment Temperature**
 - Hot Case +21 C
 - Cold Case -51 C
- **Effective emittance = 0.03**
- **White Beta Cloth outer layer**
- **Fluid mass flow rate: 155 kg/hr**



Hot & Cold Case Temperature Predictions

144

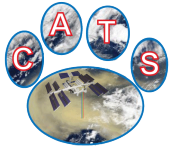
Subassembly	Part	Survival	Operational Temp	Cold	Hot
Telescope	Primary	-40 to +50 C	-10 to +45 C	19	34
	secondary	-40 to +50 C	-10 to +45 C	17	33
	metering structure	-40 to +50 C	-10 to +45 C	17	34
	interface plate	-40 to +50 C	-10 to +45 C	18	34
	secondary mirror baffle	-40 to +50 C	-10 to +45 C	18	34
Transmitter MFOV path	Laser 1 Diodes	0 to +50	+24 to +26		
	LOM Coldplate	-10 to +50	+10 to +40	25	35
	LEM Coldplate	-10 to +50	+10 to +40	27	37
	laser 1 beam expander	-30 to +50	+10 to +40	18	37
	power beam splitter	-30 to +50	+10 to +40	18	37
	fold mirror	-30 to +50	+10 to +40	18	37
	Left View rotation stage 1	-10 to +50	+10 to +40	18	37
	Left View rotation stage 2	-10 to +50	+10 to +40	18	37
	Right View rotation stage 1	-10 to +50	+10 to +40	18	37
	Right View rotation stage 2	-10 to +50	+10 to +40	18	37
Transmitter CPL and HSRL Path	Laser 2 Diodes	0 to +50	+24 to +26		
	LOM Coldplate	-10 to +50	+10 to +40	23	33
	LEM Coldplate	-10 to +50	+10 to +40	21	33
	Laser Path Select Stage	-10 to +50	+10 to +40	15	33
	HSRL Beam Expander	-30 to +50	+10 to +40	15	33
	HSRL Fold Mirror	-30 to +50	+10 to +40	15	33
	HSRL Rotation Stage 1	-10 to +50	+10 to +40	15	33
	HSRL Rotation Stage 2	-10 to +50	+10 to +40	15	33
	HSRL Rotation Stage 3	-10 to +50	+10 to +40	15	33
	THG	-20 to + 60	0 to +45	20	33
	CPL Beam Expander	-30 to +50	+10 to +40	15	33
	CPL Fold Mirror	-30 to +50	+10 to +40	15	33
	CPL Rotation Stage 1	-10 to + 40	+10 to +40	15	33
	CPL Rotation Stage 2	-10 to + 40	+10 to +40	15	33



Hot & Cold Case Temperature Predictions

145

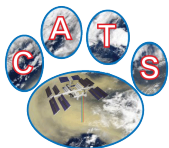
Data System	DSRM PDA	-65 to +150 -65 to +150	-40 to +70 -40 to +90	27 39	41 51
HSRL detector box	(All other detector boxes off during operation)				
	SPCM (1064 II)	-20 to +70	+5 to +40	21	33
	SPCM (1064 \perp)	-20 to +70	+5 to +40	21	33
	etalon	-10 to +50	+39 to +41	21	33
	HSRL optics train	-10 to +50	+10 to +40	21	33
	detector electronics	-10 to +50	+10 to +40	21	33
	etalon electronics	-10 to +50	+10 to +40	21	33
	pressure sensor	-20 to +70	-10 to +60	21	33
CPL detector box	(All other detector boxes off during operation)				
	PMT (355 II)	-20 to +55	+5 to +45	22	33
	PMT (355 \perp)	-20 to +55	+5 to +45	22	33
	SPCM (532 II #1)	-20 to +70	+5 to +45	22	33
	SPCM (532 II #2)	-20 to +70	+5 to +45	22	33
	SPCM (532 \perp #1)	-20 to +70	+5 to +45	22	33
	SPCM (532 \perp #2)	-20 to +70	+5 to +45	22	33
	SPCM (1064 II)	-20 to +70	+5 to +45	22	33
	SPCM (1064 \perp)	-20 to +70	+5 to +45	22	33
	pressure sensor	-20 to +70	-10 to +60	22	33
Starboard View Detector Box	(Nominally operated with Port View Detector Box)				
	SPCM (532 II #1)	-20 to +70	+5 to +45	22	34
	SPCM (532 II #2)	-20 to +70	+5 to +45	22	34
	SPCM (532 \perp #1)	-20 to +70	+5 to +45	22	34
	SPCM (532 \perp #2)	-20 to +70	+5 to +45	22	34
	SPCM (1064 II)	-20 to +70	+5 to +45	22	34
	SPCM (1064 \perp)	-20 to +70	+5 to +45	22	34
	pressure sensor	-20 to +70	-10 to +60	22	34



Hot & Cold Case Temperature Predictions

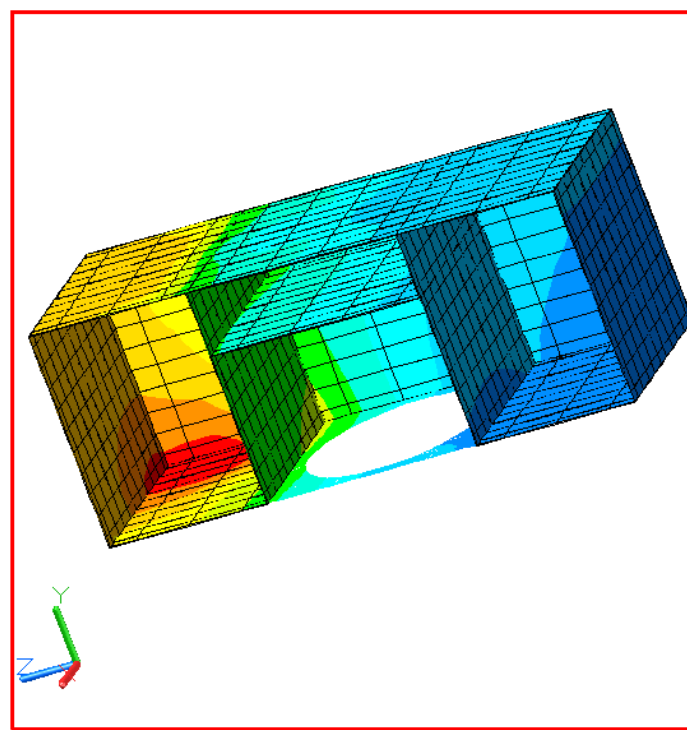
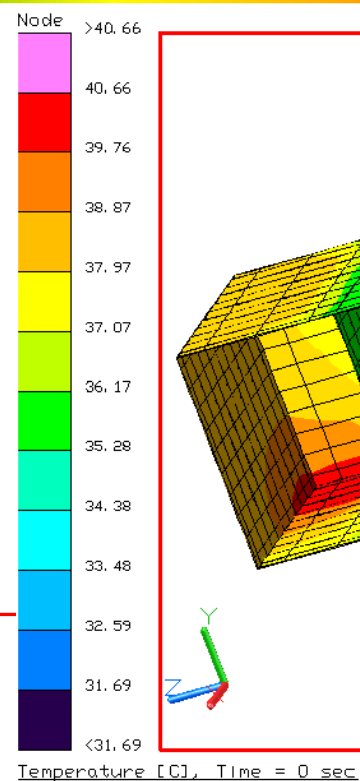
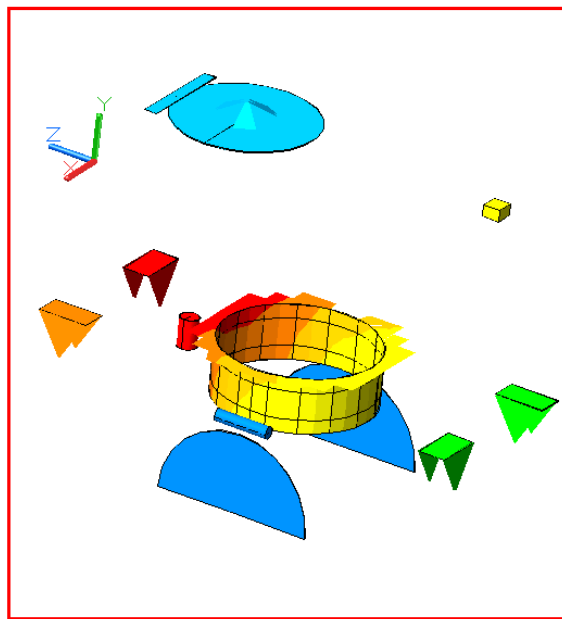
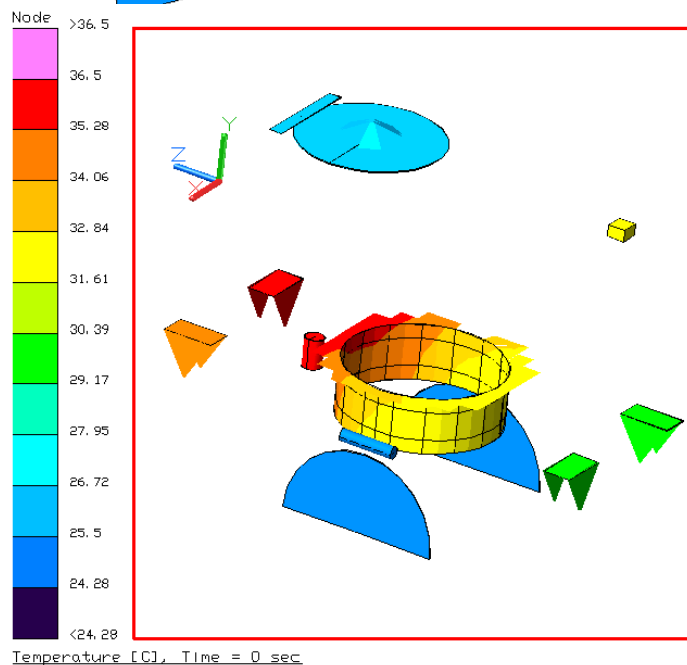
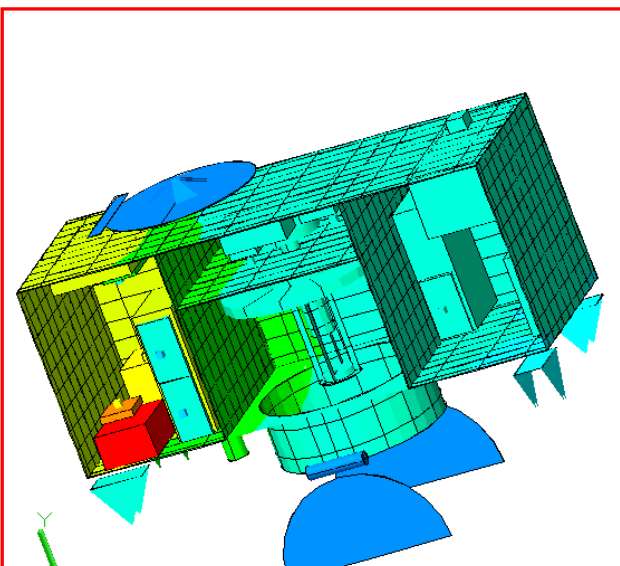
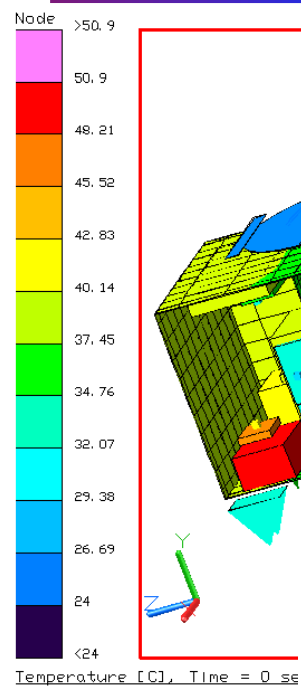
146

Port View Detector Box	(Nominally operated with Starboard View Detector Box)				
	SPCM (532 II #1)	-20 to +70	+5 to +45	22	34
	SPCM (532 II #2)	-20 to +70	+5 to +45	22	34
	SPCM (532 ⊥ #1)	-20 to +70	+5 to +45	22	34
	SPCM (532 ⊥ #2)	-20 to +70	+5 to +45	22	34
	SPCM (1064 II)	-20 to +70	+5 to +45	22	34
	SPCM (1064 ⊥)	-20 to +70	+5 to +45	22	34
	pressure sensor	-20 to +70	-10 to +60	22	34
Door Assembly	door motor assembly	-55 to +75	-45 to +65	-21	25
	door interlock	-20 to +70	-10 to +60	7	36
Housing	H-Fixture	-101 to +121	-101 to +121	20	32
	PIU	-45 to +79	-45 to +65	N/A	N/A
	FRGF Grapple	-156 to +121	-76 to +68	-17	26
	HCAM-P	-65 to +150	-50 to +70	8	37
	HCSM-P	-65 to +150	-50 to +70	18	36



Hot Case: Entire System & Panels & Exterior Items

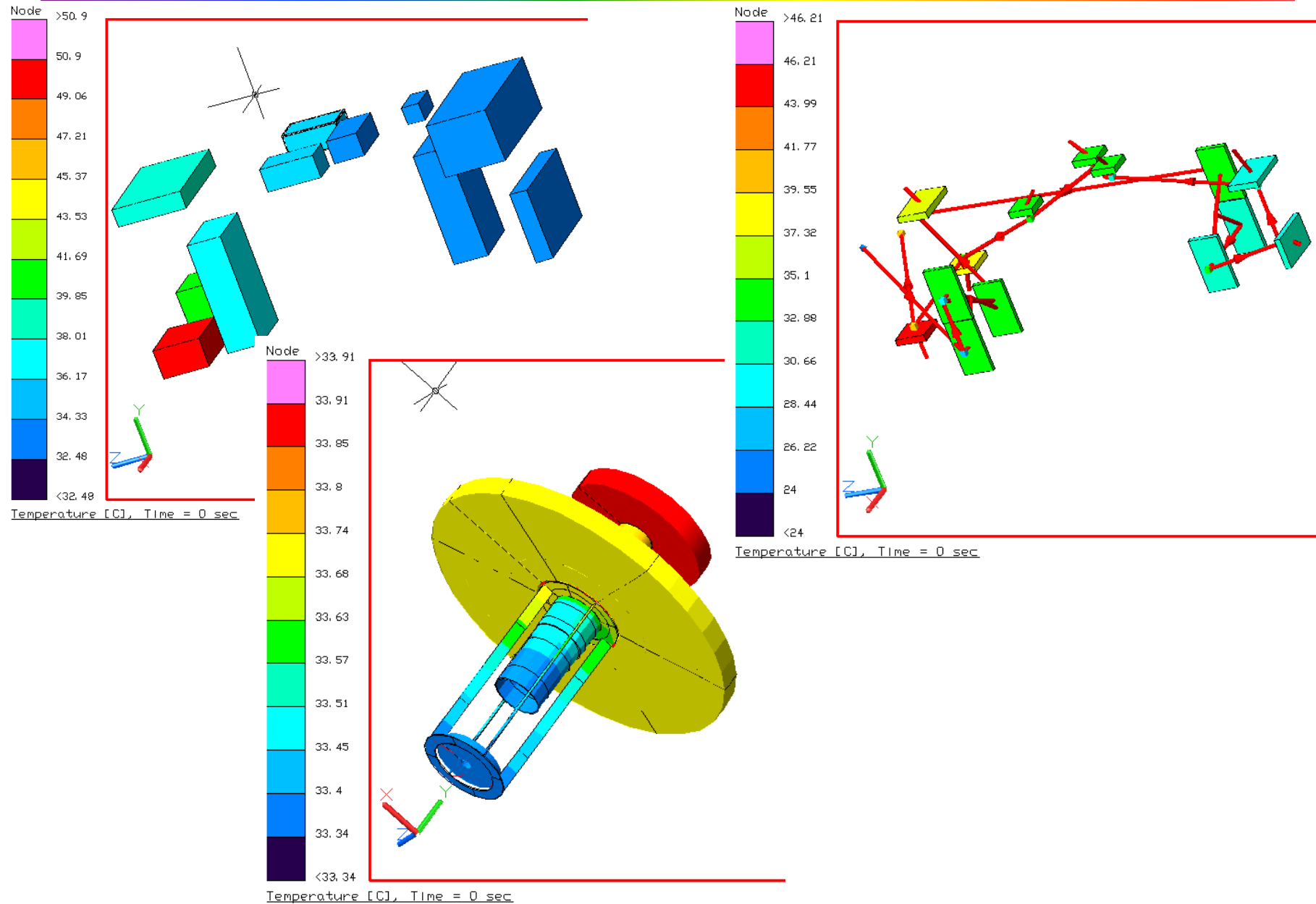
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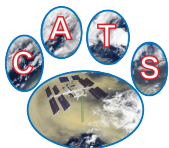




Hot Case: Electronics Boxes, Fluid Loop and Cold Plates, & Telescope Assembly

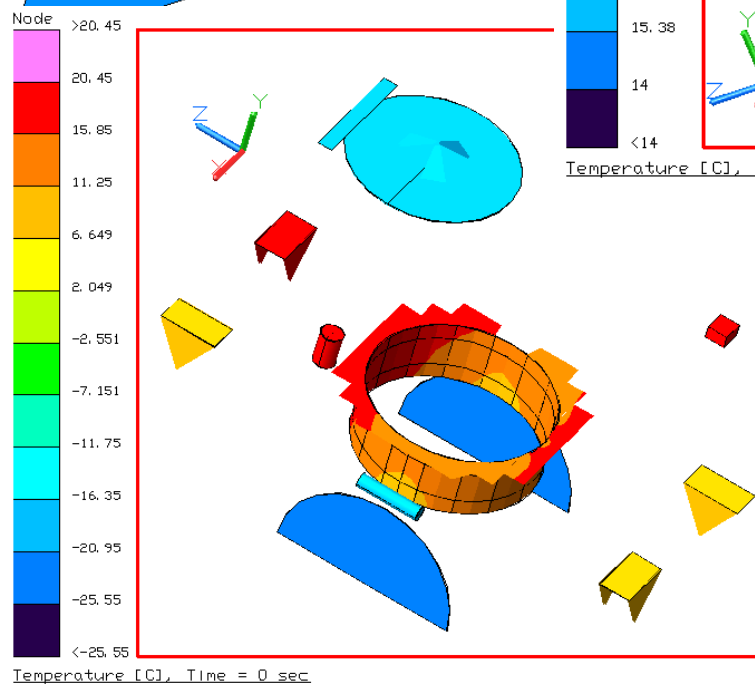
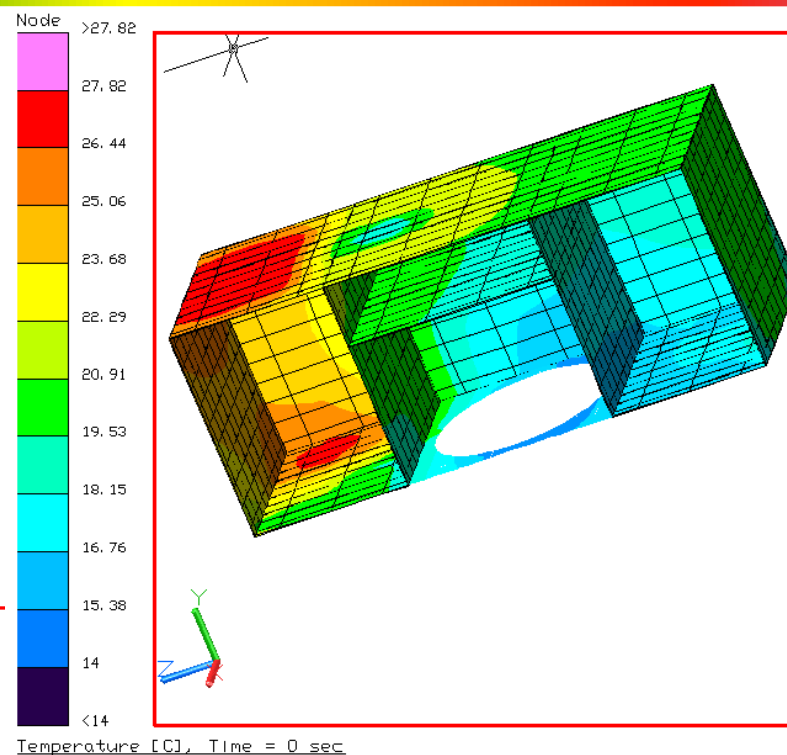
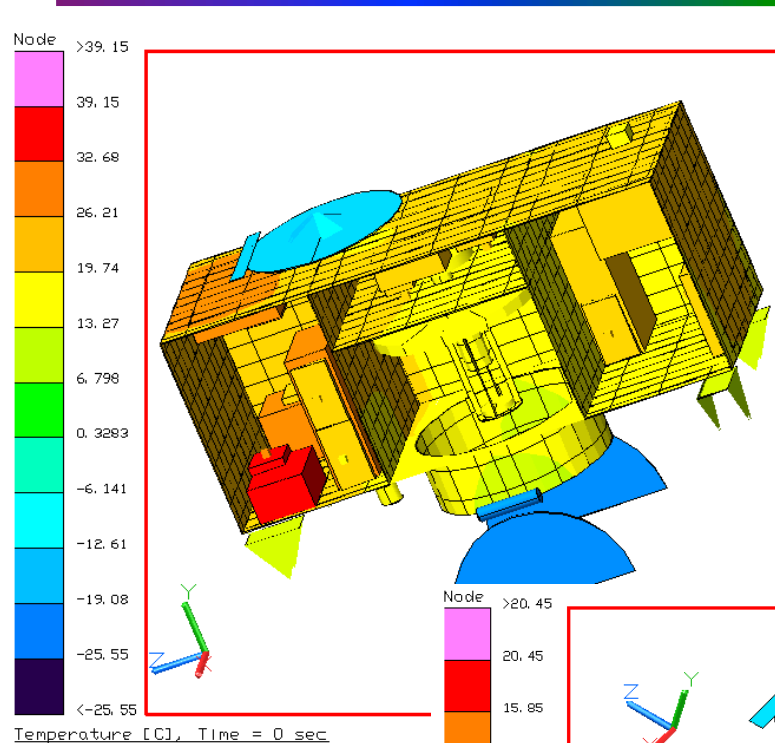
148





Cold Case: Entire System & Panels & Exterior Items

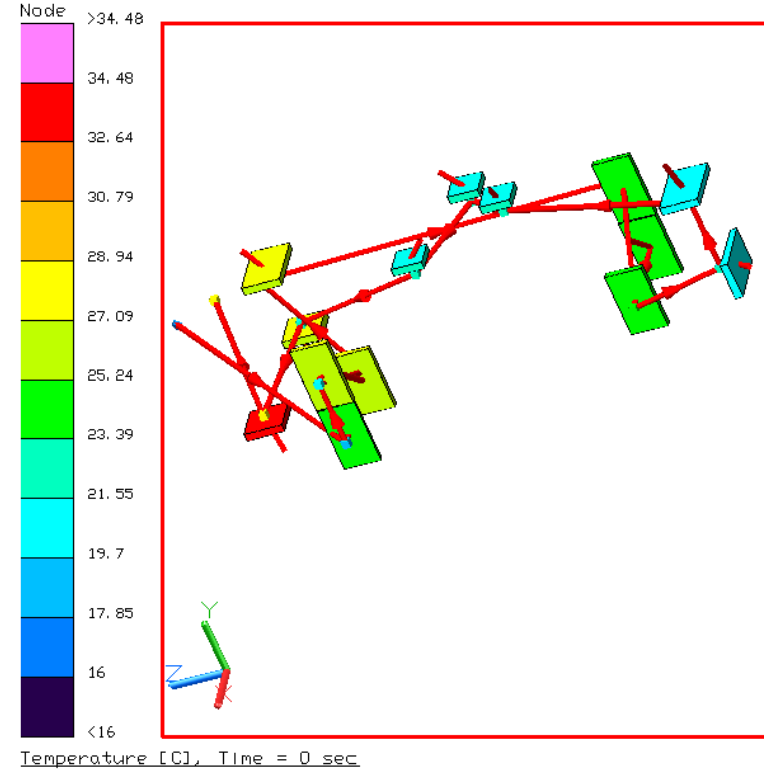
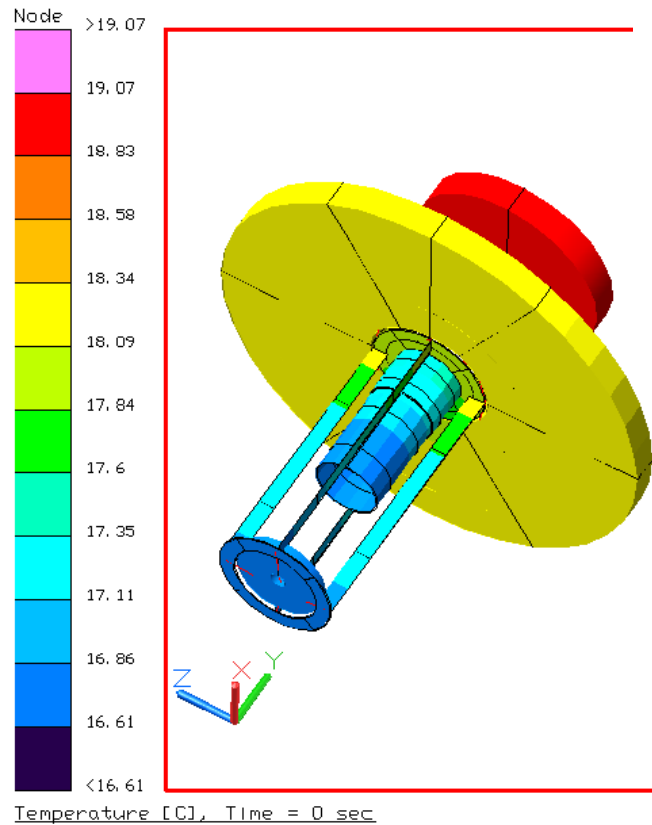
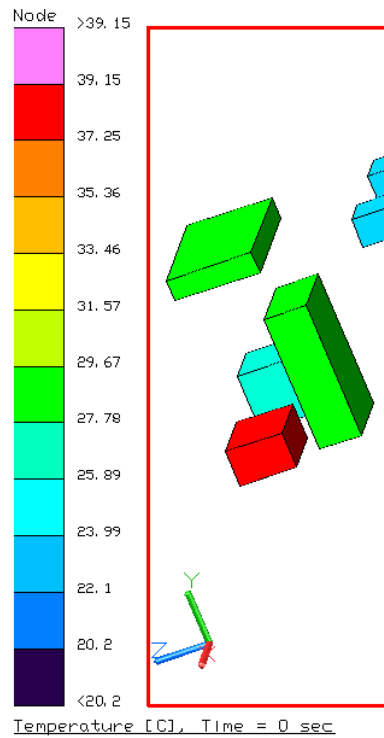
149

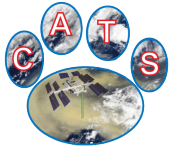




Cold Case: Electronics Boxes, Fluid Loop and Cold Plates, & Telescope Assembly

150

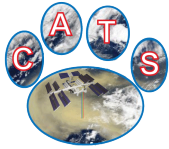




Conclusions

151

- **Key thermal requirements, interfaces, and design drivers have been identified and accounted for in the design. They include:**
 - Temperature range and stability requirements
 - ISS environments
 - JEM-EF interfaces
- **Preliminary thermal design has been developed and utilizes standard thermal control hardware**
- **On-orbit hot and cold case orbit average analyses are completed**
 - Results show requirements met with margin
- **Feasibility of thermal design approach demonstrated.**



Future Work

152

- **Finish audit of thermal requirements.**
- **Add PIU to thermal model**
- **Design fluid system –**
 - Specify components, develop pressure drop estimates
- **Add detailed model to ISS thermal model**
- **Safety Analyses, Safety Action Items and Hazard Report inputs;**
 - EVA touch temperature analysis
 - MDP calculation
 - Material compatibility
- **Detailed design effort in support of CDR**
- **Run other operational and nonoperational cases**
 - Safe Hold Mode, Laser 2 CPL Mode, Laser 2 HSRL Mode, Alignment Mode
- **Launch phase & transport analysis with detailed thermal model**
- **Supply JAXA, HTV, SpaceX with TRASYS / SINDA reduced model**
- **Specify and procure all thermal hardware**
- **Integration support**
- **Develop thermal vacuum / thermal balance test plan and procedure**
- **Support flight rule development, launch, and mission operations**



Electrical Systems

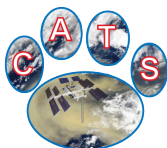
John Cavanaugh/554



Functional Requirements Summary

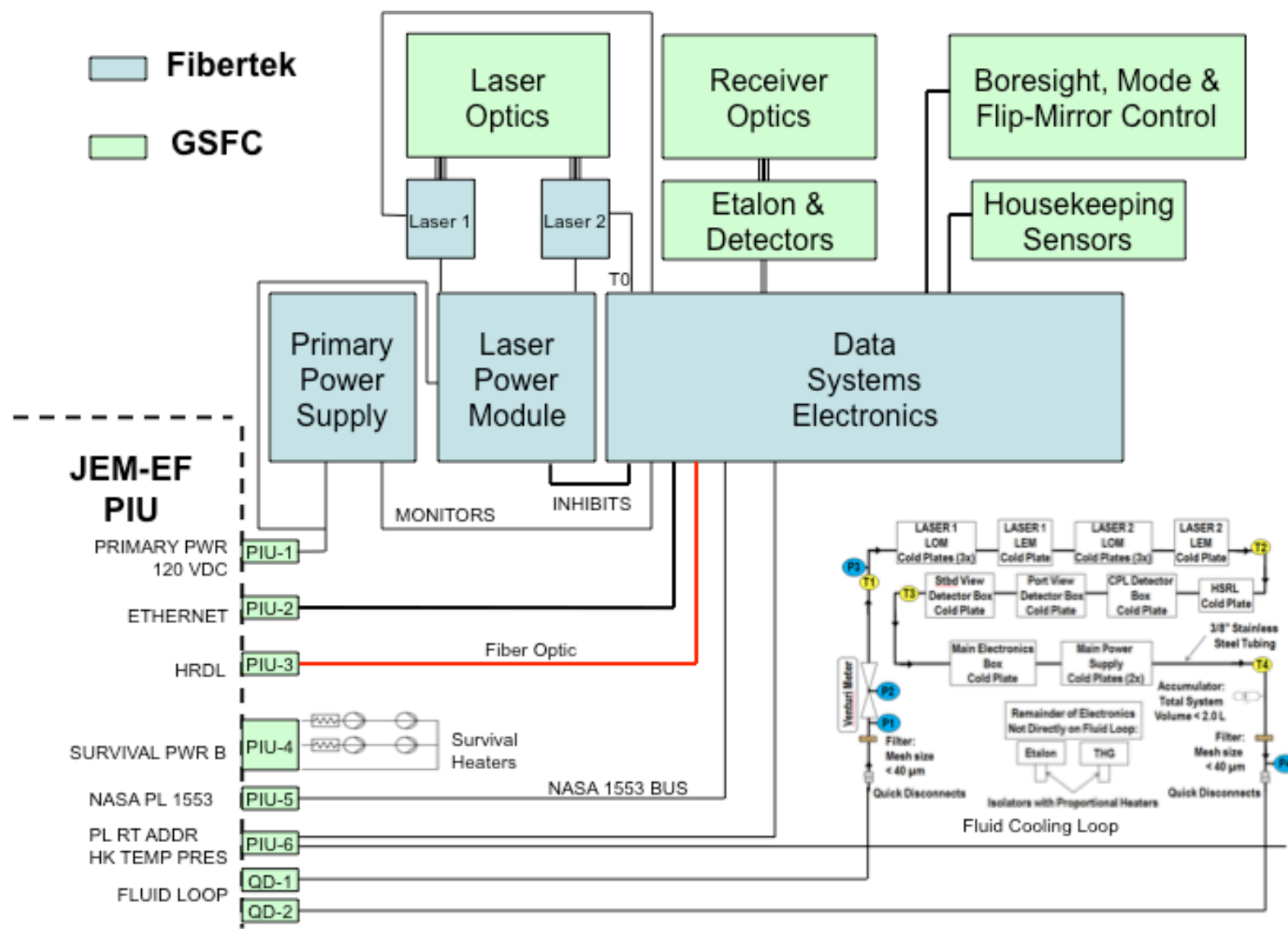
154

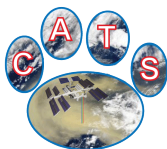
- **Provide conditioned secondary and tertiary power to all subsystems**
 - Single 120 VDC primary power circuit from JEM-EF
- **Control laser transmitters :**
 - **Ground command implementation :**
 - Laser selection
 - Two-fault tolerant safety interlocks
 - **Fault interlocks**
 - over-temp, over-current, door
- **Acquire and store detector photon counts**
 - **Multichannel scaler :**
 - Timing referenced to laser fire
 - Bin size 200 ns
- **Control mechanisms via ground command :**
 - Alignment motors
 - Wavelength selection stage
 - Door motors & launch locks
- **Monitor instrument health**
 - Temperature, pressure, flow, voltages, currents, laser energies
- **Packetize, store and transmit instrument data :**
 - Housekeeping via 1553
 - Science data via either HRDL or Ethernet



CATS Block Diagram

155

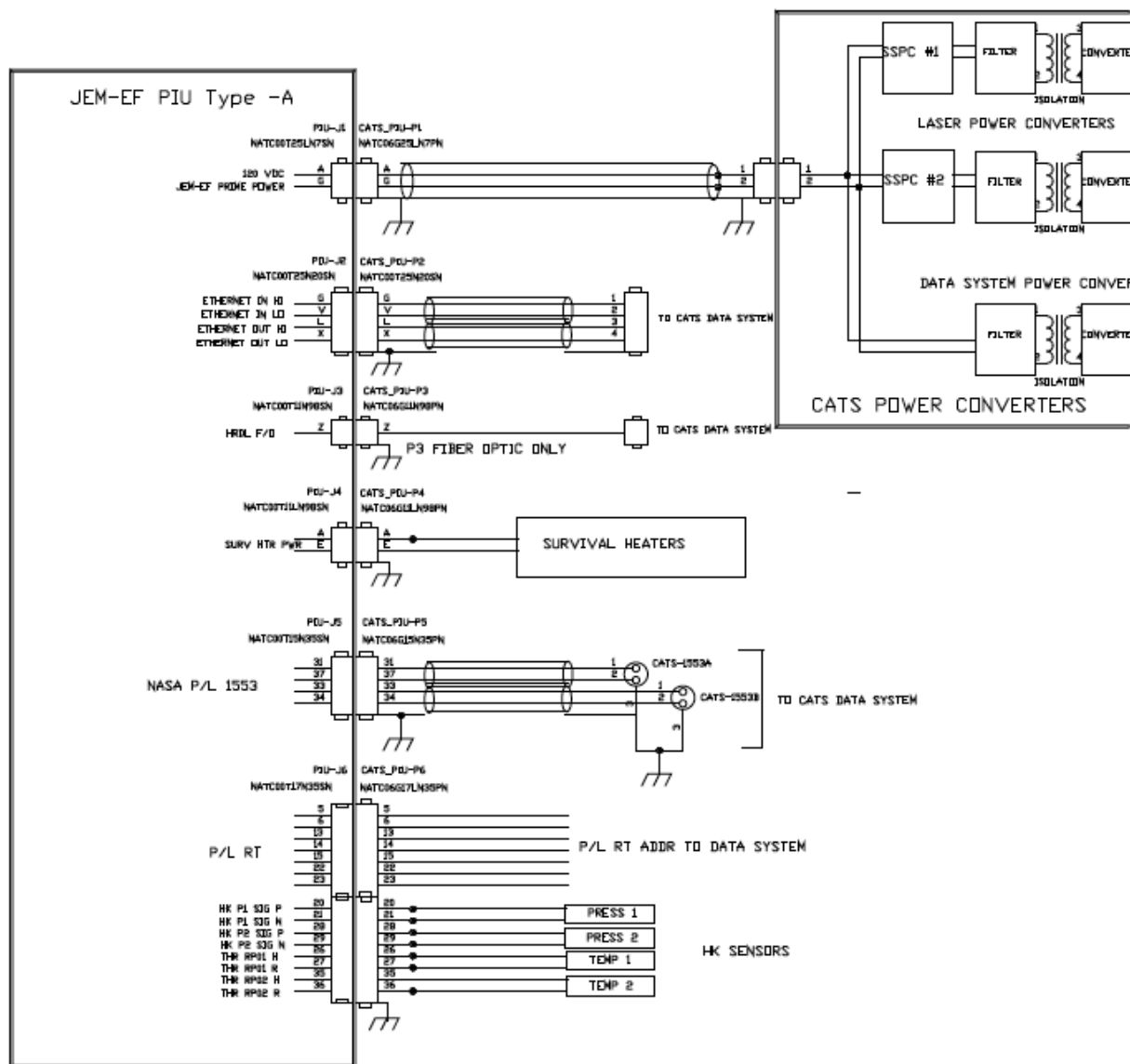


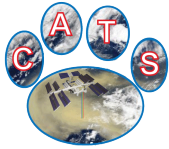


JEM-EF Interfaces

156

**Electrical Interfaces
defined by
NASDA-ESPC-2900A**





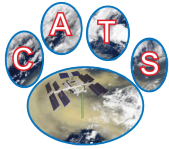
JEM-EF Interfaces - Power

157

- **Primary Instrument Power**
 - **Single circuit**
 - **2 #8 AWG contacts**
 - **3 kW available power**
- **Survival Power**
 - **Single circuit**
 - **2 #20 AWG contacts**
 - **100 W available**

Table 3.5.1-1 EF Electrical Power Supply Characteristics

Parameter	Specifications
Voltage range in steady state (main power)	112.5 to 126 [VDC]
Voltage range in steady state (survival power)	110.5 to 126 [VDC]
Maximum ripple voltage	3.0 [V] (peak-to-peak)
Maximum ripple voltage spectrum	(See SSP30482, Vol.1 Paragraph 3.1.4.1.3.)
Transient voltage	(See SSP30482, Vol.1 Paragraph 3.1.4.1.4.)
(main power)	95.5 to 143.1 [V]
(survival power)	93.5 to 143.1 [V]
Maximum transient recovery time	(See SSP30482, Vol.1 Paragraph 3.1.4.1.5.)
Power impedance (source side)	(See SSP30482, Vol.1 Paragraph 3.1.4.1.6.)
Abnormal transient voltage	(See SSP30482, Vol.1 Paragraph 3.1.4.2.1. and 3.1.4.2.2.)
Abnormal operation voltage	(See SSP30482, Vol.1 Paragraph 3.1.4.2.3.)
RPC power rising/dropping property	See Figure 3.5.1-3.

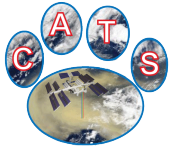


Power Allocations

158

Subsystem	QTY	Maximum Power	Allocation	Margin
SPCM Operational (40C)	16	107	128	
Photon Counting Head	2	2	2	
Flip Mirror	1	16	19	
Bore-Sight Assembly	9	26	31	
Etalon and Electronics	1	19	23	
Telescope Cover Assembly	8	46	55	
DSEM	1	80	96	
Laser + Electronics + Converter	1	500	600	
TOTAL		795	954	20%

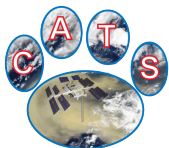
- Allocations based on maximum estimated power draw + 20%
- JEM-EF can provide up to 3 kW power



JEM-EF Interfaces - Wire Sizes and Fusing

159

CATS-ISS Wire Size and Fusing Table									
Rev- 2-Aug-11									
Circuit Description	From	To	Voltage	Max. Load Current (A)	Wire Size (AWG)	Number of Wires	Wire Length (m)(approximate)	Bundle	Fuse Rating (max. blow A)
JEM-EF Prime Power	PIU-J1	Power Converter Assembly	120 VDC	14	8	1	0.5	No	-
PCA Internal Distribution	PCA-J1	Laser Power Converter #1	120 VDC	6	16	2	0.5	Yes	20
PCA Internal Distribution	PCA-J1	Laser Power Converter #2	120 VDC	6	16	2	0.5	Yes	20
PCA Internal Distribution	PCA-J1	Data System Power Converter	120 VDC	2	20	2	0.5	Yes	6
Laser Power Converter #1	PCA-J2	Laser Electronics Module #1	28 VDC	18	10	2	0.5	Yes	27
Laser Power Converter #1	PCA-J3	Laser Electronics Module #2	28 VDC	18	10	2	1	Yes	27
Data System Power Converter	PCA-J4	DSEM	28 VDC	3.5	20	2	0.5	Yes	10
Detector Box 1 Power	DSEM	Detector Box 1	5 VDC	3	20	2	1	Yes	10
Detector Box 2 Power	DSEM	Detector Box 2	5 VDC	3	20	2	1	Yes	10
Motor Controller Power	DSEM	Motor Controller	5 VDC	3	20	2	1	Yes	10
Survival Heaters-JEM-EF	PIU-J4	Heaters	120 VDC	1	20	1	2	No	-
Survival Heaters - Launch Vehicle	TBD	Heaters	50	1	20	1	1	No	-
SPCM Detector HV	SPCM Power Converter	Detector Box 1, 2	500	5.00E-06	Ckt Trace	1	0.05	No	N/A
PMT Detector HV	PMT Power Converter	Detector Box 1	1000	1.00E-06	Ckt trace	1	0.05	No	N/A
Laser Q-Switch HV	Laser Electronics Module	Laser Optics Module	3200	1.00E-06	28	1	0.5	No	N/A
Laser Dioda Array Current (pulsed)	Laser Electronics Module	Laser Optics Module	30	50	18	4	0.5	yes	N/A



JEM-EF Interfaces – Command & Data

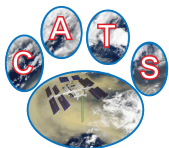
160

Table 3.5.2-1 Data Interface Characteristics

Item	NASA PL Bus	High-rate data system	Video system	Payload HK data		Medium-rate data system (Ethernet)	Local bus PL-JEM system
				Temperature data	Pressure data		
Transmission mode	MIL-STD-1553B	FDDI		Analog		IEEE 802.3	
Medium	Twin-axial cable	Optical fiber		Twist-pair Shielded cable		Twin-axial cable	
Transmission route data rate (max.)	1 Mbps	100 Mbps		-		10 Mbps	
Number of channels	A-system 1/ B-system 1	1		A-system 1/ B-system 1	A-system 1/ B-system 1	1	
Data type	Low-rate experiment data Command/telemetry	High-rate experiment data		Telemetry		Medium rate experiment data Command/telemetry	
Remarks	For all EFU positions	In 8 EFU positions (#1, 2, 3, 4, 5, 6, 8, 9)		For all EFU positions	For all EFU positions	In 7 EFU positions (#1, 2, 3, 6, 9, 11, 12)	

- All commanding done via NASA PL 1553 bus
- Housekeeping and sample science data telemetry :
 - transmitted via 1553 at 640 words per 100 ms slot
 - 1553 schedule allocation TBD
- Science Data average rate ~2 Mbits/s
 - Transmitted via FDDI or Ethernet
 - Path selectable by ground command

[illegible]

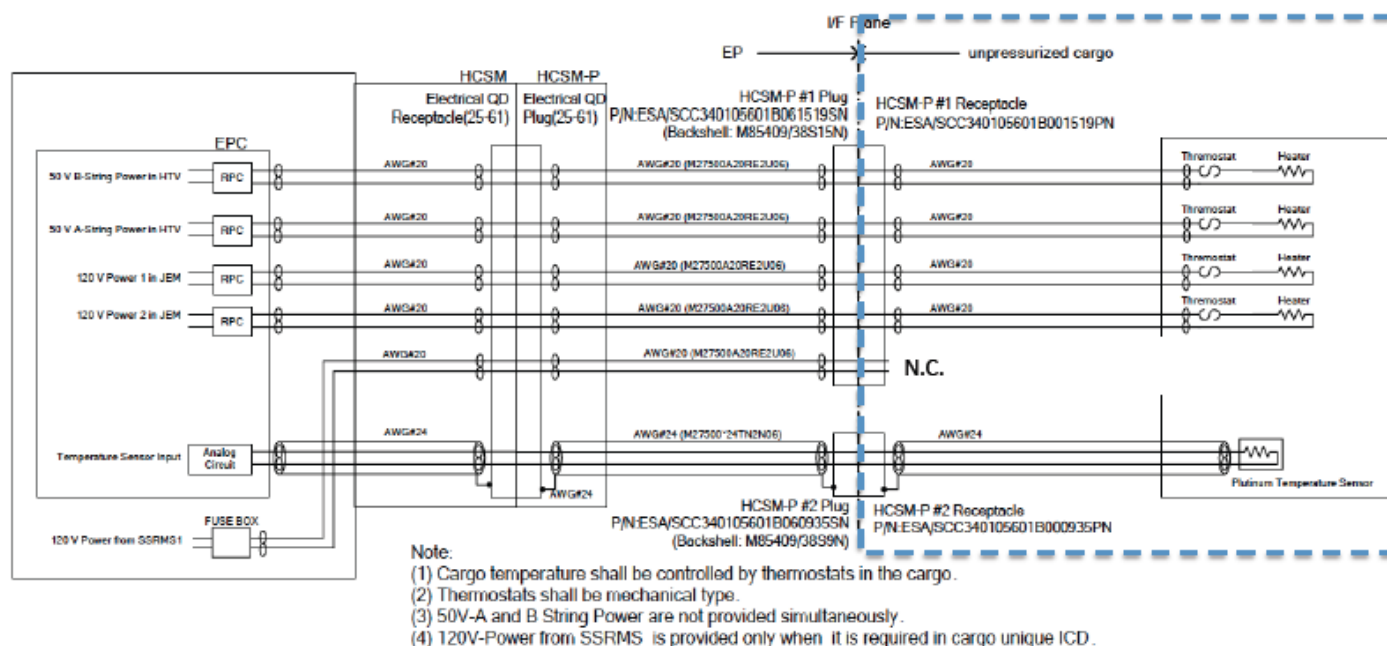


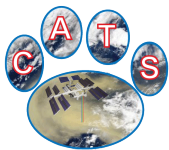
JEM-EF Interfaces – Thermal Control

162

- Operational thermal control provided by fluid loop
- Fluid temperature and pressure sensor signals provided to JEM-EF
- Survival heaters controlled by thermostats
- 100W allocation

CATS-ISS Survival Heaters – Launch and transfer
HTV/JEM-EF Configuration





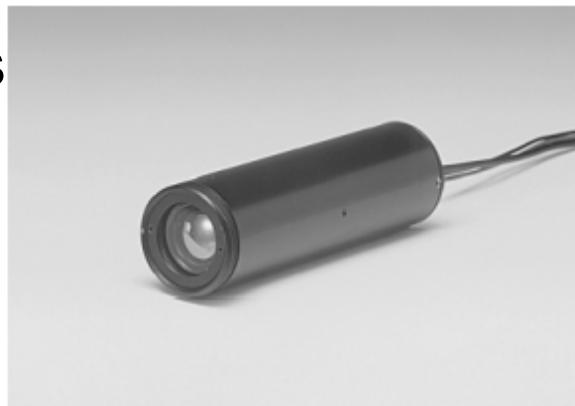
CATS Interfaces – Detectors & Etalon

163



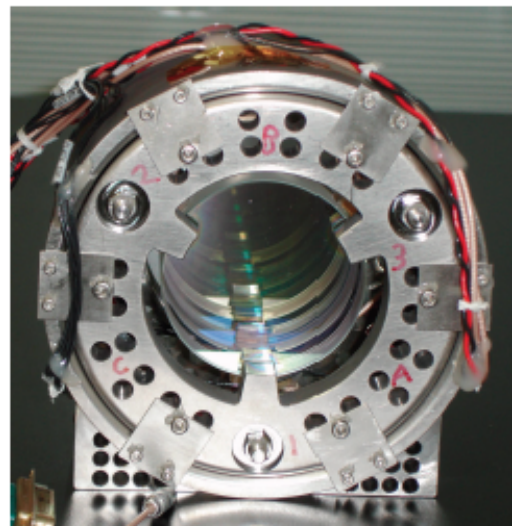
SPCM, Qty 30

Detectors

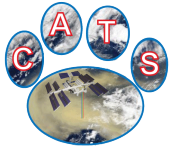


PMT, Qty 2

- **Both detector types :**
 - use 5 VDC power
 - output logic-level pulses
 - 20 MC/s maximum rate
- **Etalon (“black box”)**
 - Uses 28 VDC power
 - Accepts serial commands
 - Outputs internal H/K sensor data



Prototype etalon, in Invar mount



CATS Interfaces – Motor Control

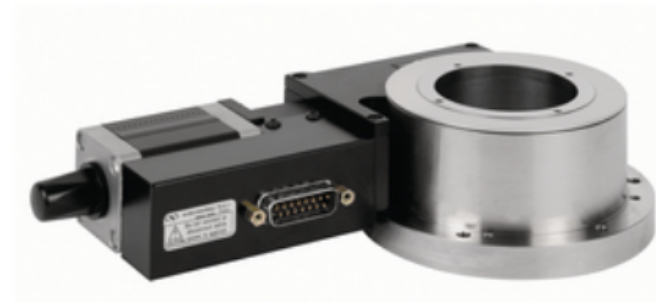
164

Rotation and Linear Translation Stages

Stages provide accurate positioning for moving parts.



Newport MFA-CCV6 Translation Stage



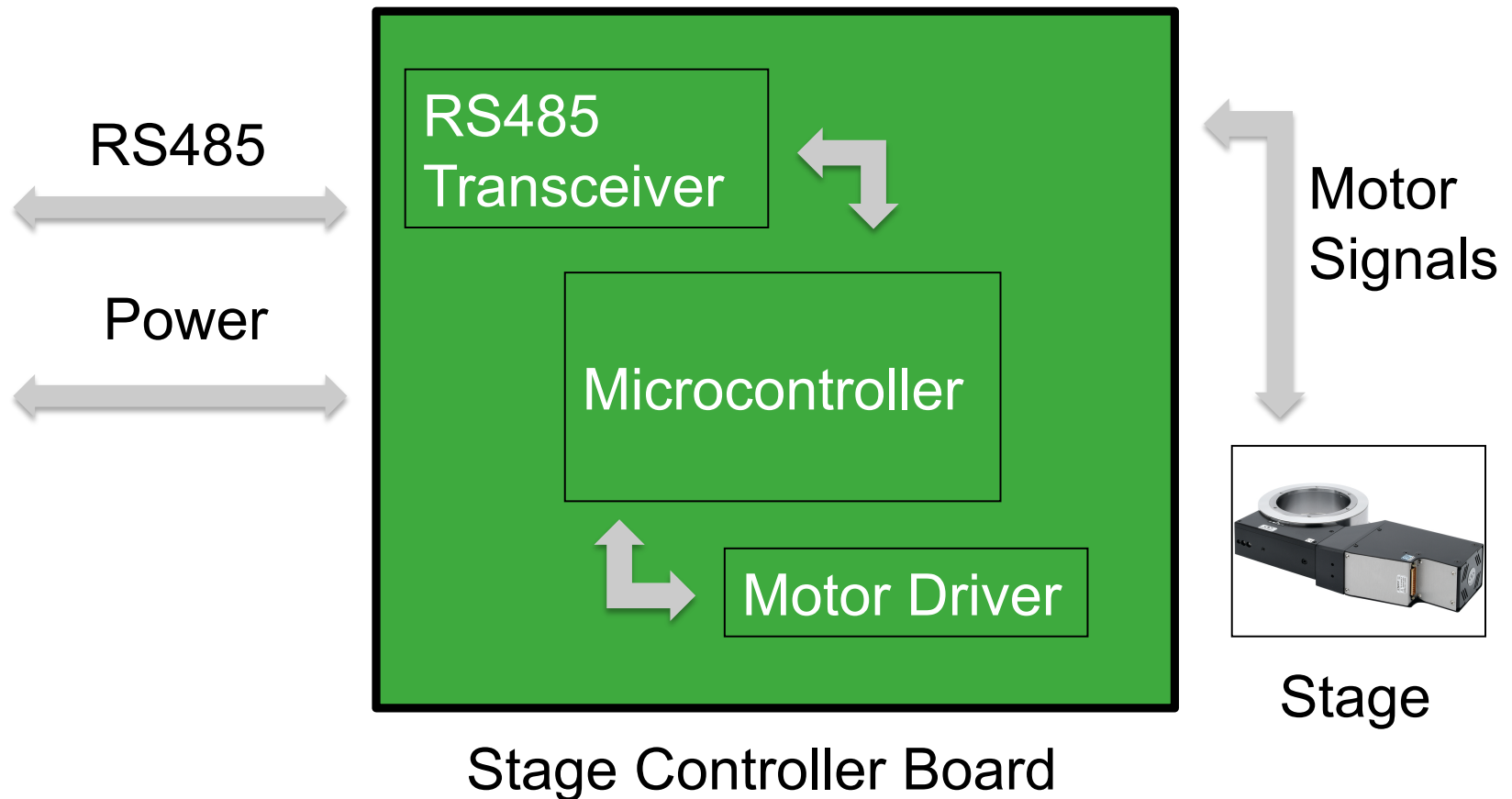
Newport RVS80PP-FV6 Rotation Stage

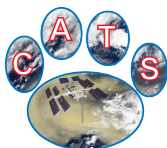


CATS Interfaces – Motor Control

165

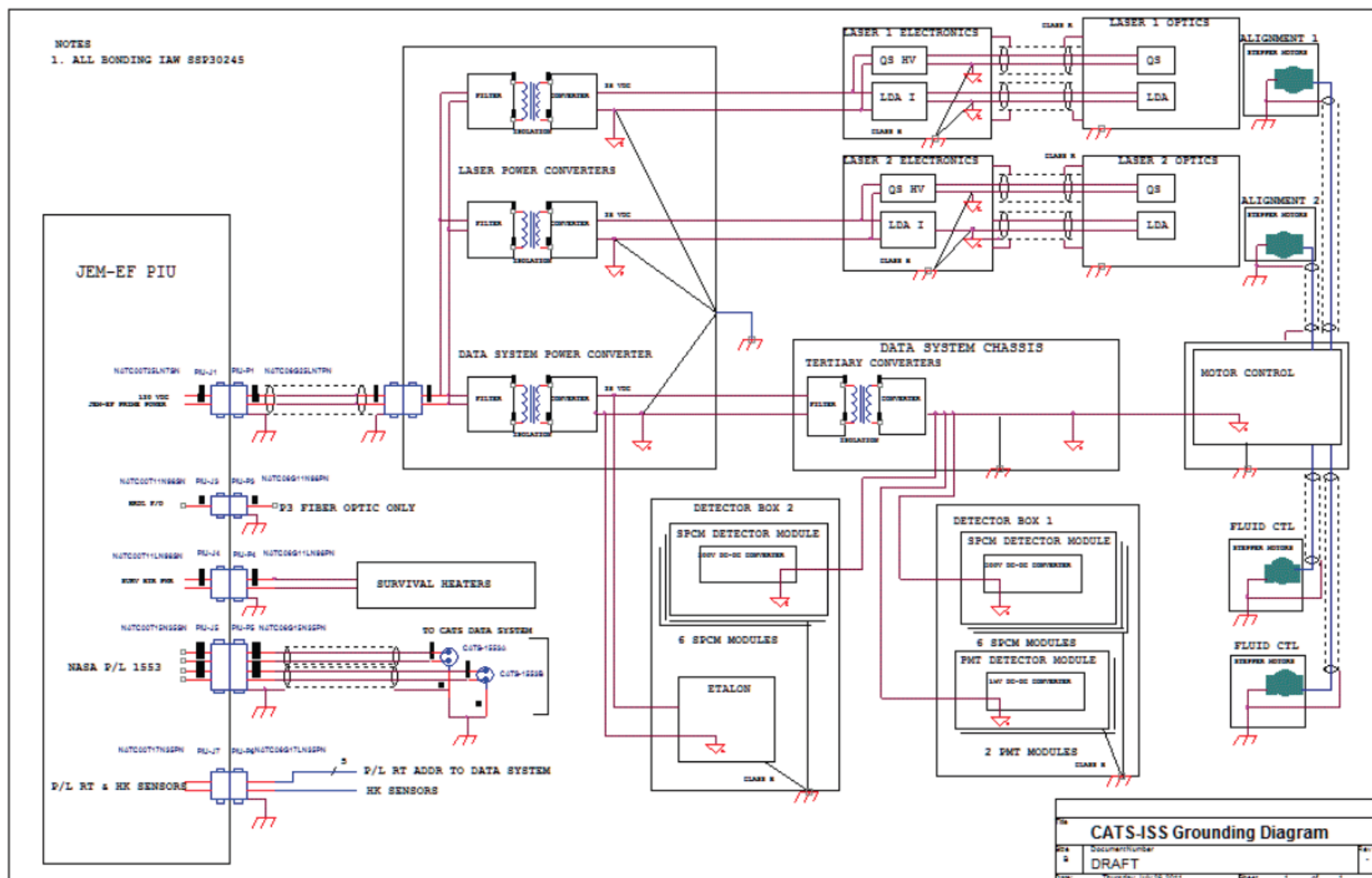
Stage controllers interface via RS485 bus with Data System Electronics Module and drive stage motors using onboard motor driver chip.

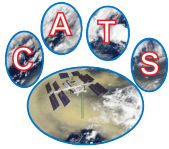




CATS Interfaces – Grounding

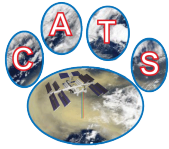
166





CATS-ISS Avionics

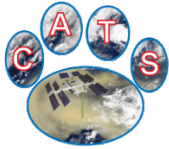
Fibertek, Inc.



Program Summary

168

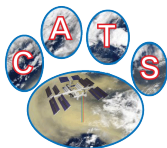
- The CATS-ISS avionics electronics program is on schedule.
- Costs are within planned parameters.
- The preliminary design is complete and is consistent with top-level requirements.
- Detailed block diagrams for each system board are complete.
- Schematic capture is underway.
- System I/O connectors have been defined.
- Laser safety control/verification design is complete.



CATS Avionics Outline

169

- System Architecture
- Data System Electronics Module
 - Secondary Power Supply (SPS)
 - Communications Board (Comm)
 - System Control Board (CB)
 - Data Capture Board (DCB)
 - Auxiliary Control Board (ACB)
 - Backplane Interface Board (BPIB)
- Power Distribution Assembly
- Safety
- Risks
- Schedule

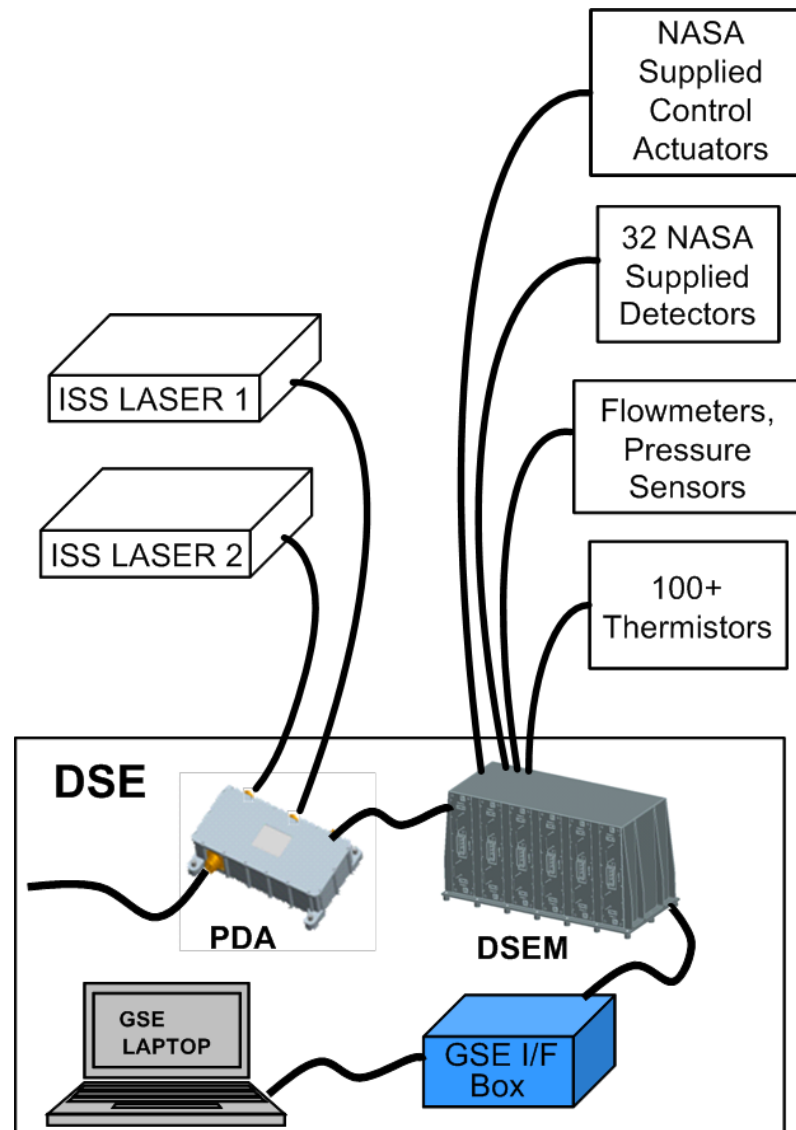


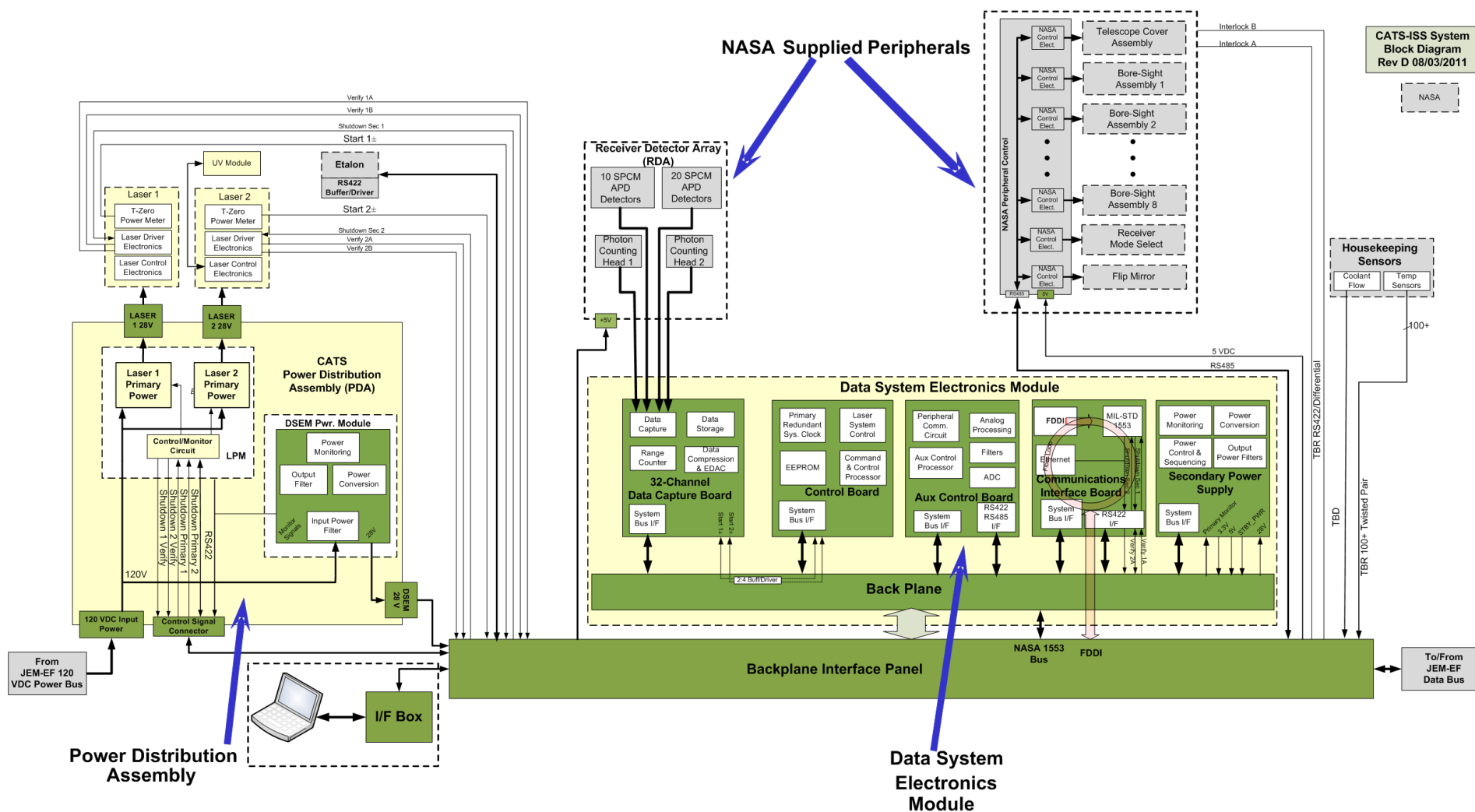
System Architecture

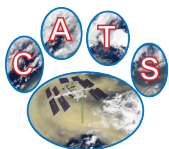
170

The naming conventions for the CATS ISS Receiver Electronics are as follows:

- The overall system is referred to as the Data Systems Electronics (DSE)
- The DSE is comprised of two major subassemblies:
 1. **Data System Electronics Module (DSEM)**
 - circuit card cage assembly which includes circuit cards to operate the CATS LIDAR
 - Includes electrical, mechanical, thermal and SW interfaces to the ISS
 2. **Power Distribution Assembly (PDA)** –
 - provides power for the DSEM and the two ISS lasers
- The DSE has numerous interfaces to NASA-supplied peripherals devices
- The DSE also includes a laptop, interface box and software used as Ground Support Equipment (GSE)
- Software will use NASA-supplied TReK interface protocol

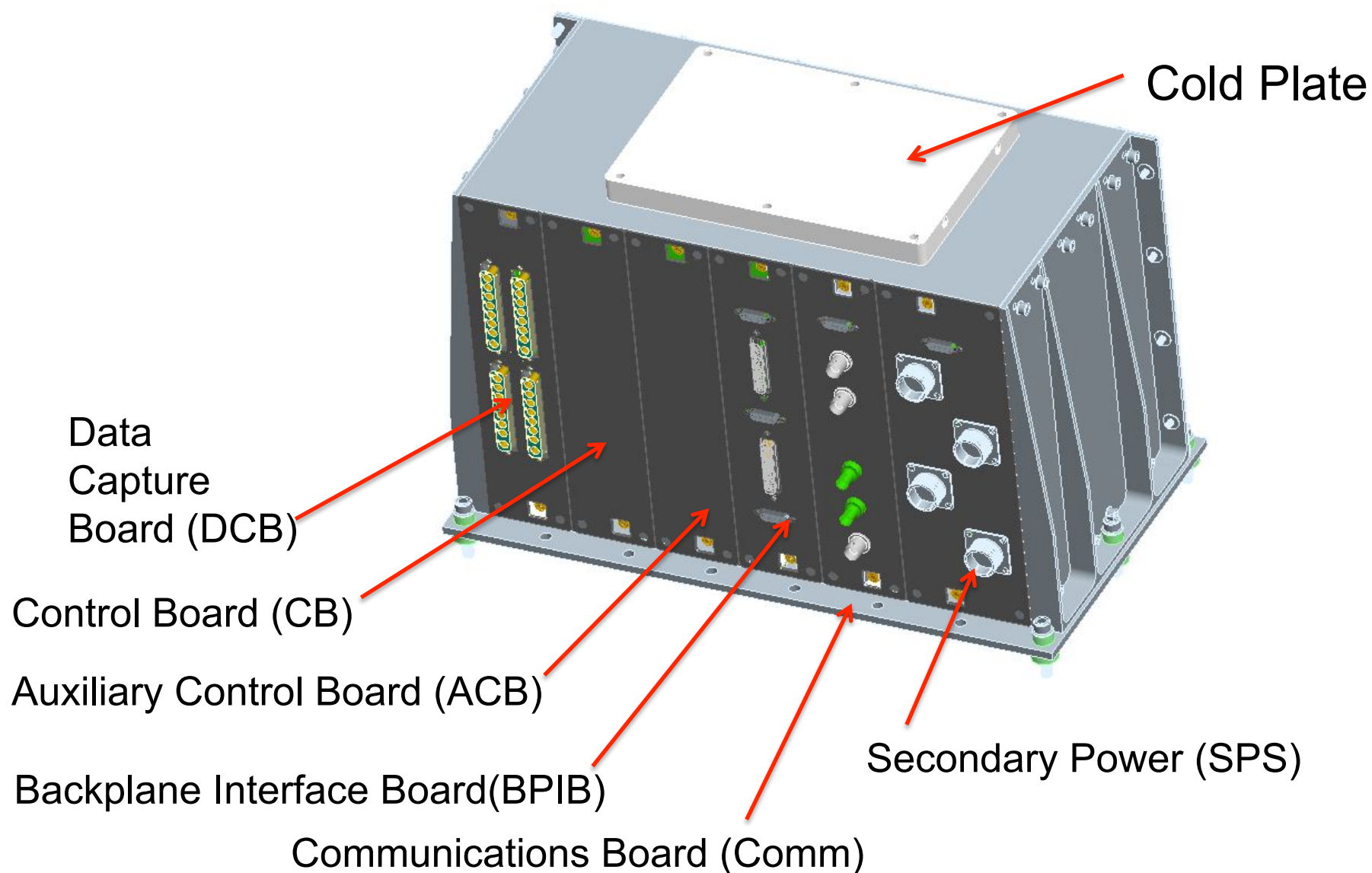


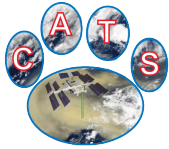




DSEM Chassis Assembly

172





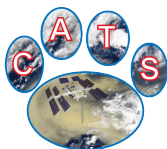
DSEM Mass and Power

173

- Overall Dimensions: 15" x 10" x 8"
- Mass: 36 Lbs
- DSEM Input Power:
 - Min: 86W (Standby Power)
 - Max: 297W
- DSEM Power Dissipation: 80W

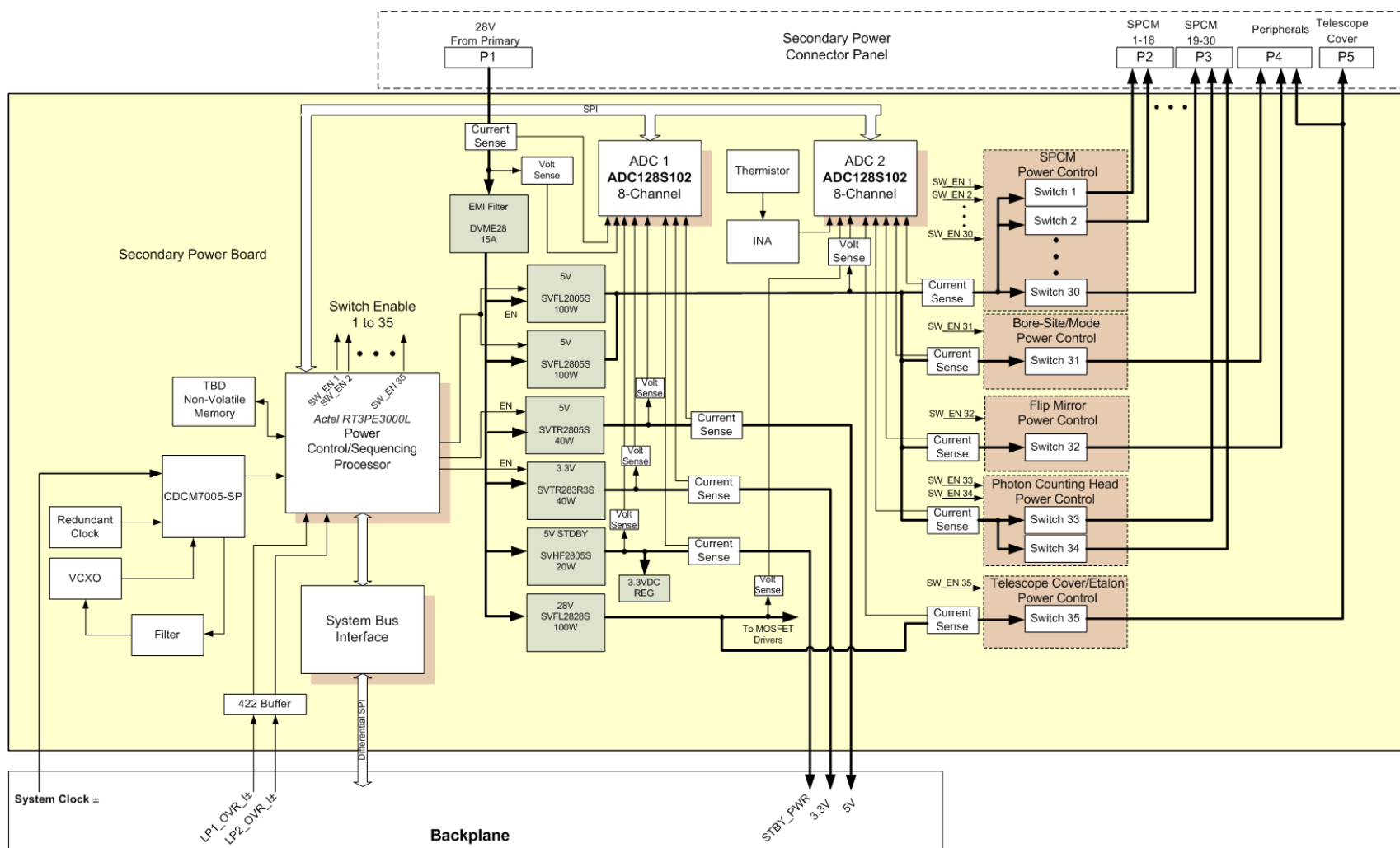


Data System Electronics

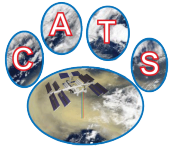


SPS Assembly

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SPS: Functions and Features

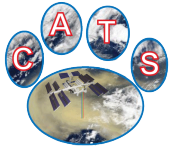
176

- **Functions**

- Peripheral Power Distribution
 - SPCM Power Control
 - Bore-site/Mode Power Control
 - Flip Mirror Power Control
 - Telescope Cover Power Control
 - Photon Counting Head Power Control
- DSEM Internal Power Distribution

- **Features**

- Actel RT3PE3000L 8051 Core Power Control Sequencing Processor
 - Provides full power sequencing.
- Monitor all voltages, currents and board temperature
- HI-Rel Space Qualified Bricks 15VDC, 5VDC & 3.3VDC
- Separate Supplies for Peripherals and Receiver Electronics
- Individual Power-up Control for all Detectors
- DVME28, 15A EMI Filter
- Synchronizes to the system clock with a local clock default as backup.



SPS: Connectors

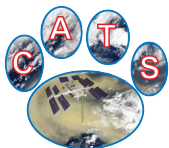
177

➤ Overview (All Connectors are Space Qualified)

- Glenair Mighty Mouse
- Square Front Flange, Solder Cup, Electroless Nickel Plated
- Solder Cup for PCB Pigtail Mount
- Modification Code 429 Meets NASA Level 2 Screening
- Operating Temperature -55C to 150C
- Outgassing process available for fluorosilicone seal
 - Code 429K – 8 hr Oven Bake 400 F
 - Code 429A – 24 hr Thermal Vacuum Outgassing at 125 C

NASA SCREENING LEVELS AND MODIFICATION CODES			
NASA Screening Level	Special Screening Only	Special Screening Plus Outgassing Processing	
		8 Hour Oven Bake 400° F.	Thermal Vacuum Outgassing 24 hrs. 125° C.
Level 1 Highest Reliability	Mod 429B	Mod 429J	Mod 429C
Level 2 High Reliability	Mod 429	Mod 429K	Mod 429A
Level 3 Standard Reliability	(Use standard part number)	Mod 186	Mod 186M

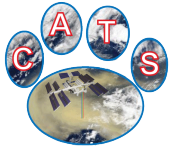




SPS: Detector Power Connectors

178

- **Two Connectors.**
 - One connector powers the first 18 SPCMs
 - The other connector powers SPCM 19-30 and the Photon Counting A/B PMTs.
 - Both connectors are the same style, but with different keying.
- **First Connector**
 - Glenair Part Number: 800-012-07 M 12-37 F N 429K
 - N (Normal) Key Position (150° of Master Key)
- **Second Connector**
 - Glenair Part Number: 800-012-07 M 12-37 F X 429K
 - X Key Position (140° of Master Key)
- **#23 Socket Contacts, Accommodates 22 AWG to 28AWG wire**
- **Solder Cup for PCB Pigtail Mount**
- **Contact Rating of 5A (EIA-364-70 Method 1)**
- **Contact Usage:**
 - Voltage= 5VDC
 - Max Current Per Contact =1.9^a
 - De-Rating = 2.63



SPS: Power Requirements

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Peripheral Power Requirements

Assembly Name	QTY	Max Power	Operational P _{ave}	Standby Power	Voltage	Max Current
SPCM Operational (40C)	16	107.00	104.00	16.00	5	21.4
Photon Counting Head	2	1.40	1.40	1.40	5.00	0.28
Flip Mirror	1	15.75	15.75	1.25	5.00	3.15
Bore-Sight Assembly	9	25.75	15.75	11.25	5.00	5.15
Etalon and Electronics	1	18.75	18.75	2.55	5.00	3.75
Telescope Cover Assembly	8	46.00	46.00	6.00	(TBD)	(TBD)

Peripherals Only

Watts

Worst Case Peak	212
Operational	202
Standby	39

Receiver Electronics

Watts

Worst Case Peak	40
Operational	40
Standby	20

Power supply Loss Based on η =82%

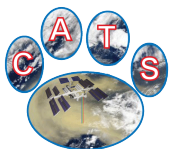
Watts

Worst Case Peak	45
Operational	40
Standby	7

Summary (Total Power Required)

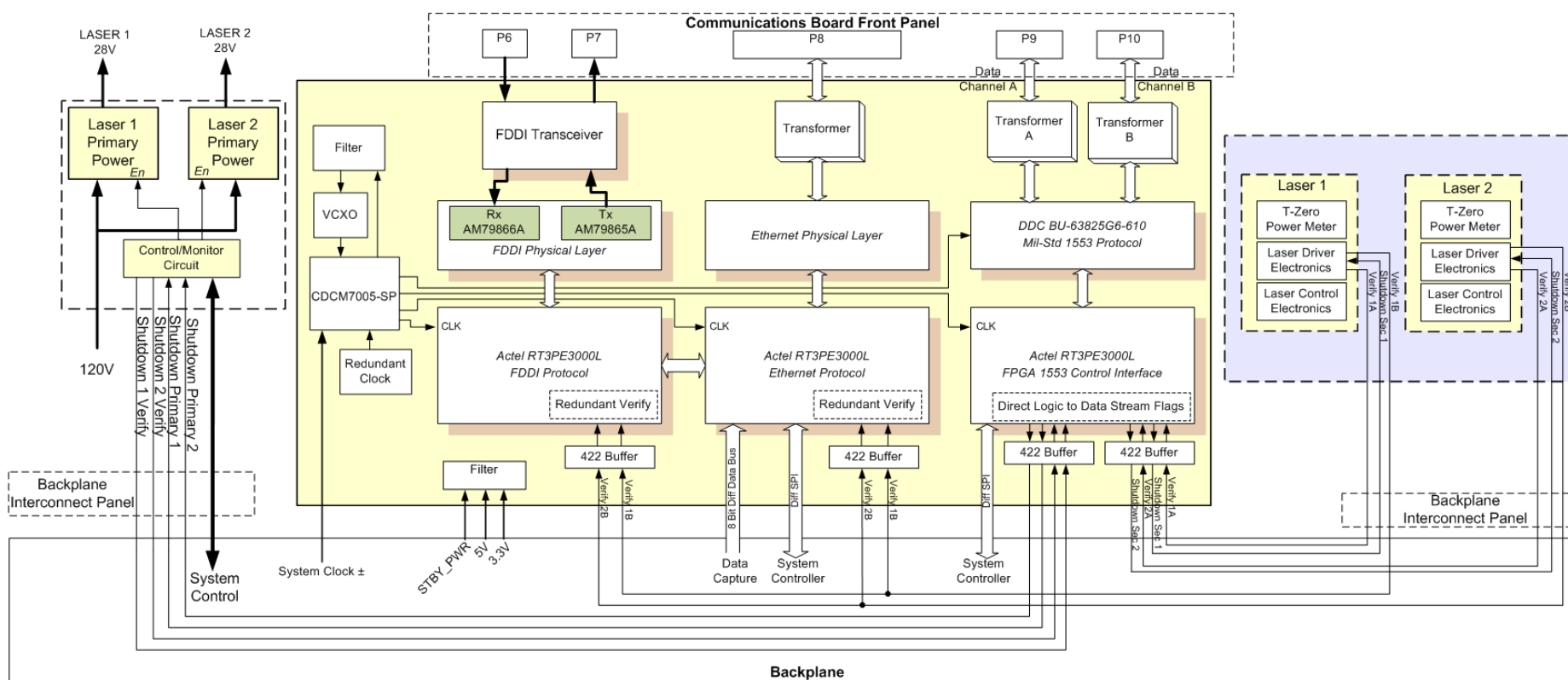
Watts

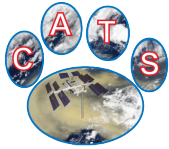
Worst Case total	297
Operational	282
Standby	86



Comm: Assembly

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Comm: Functions and Features

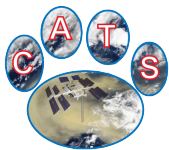
181

- **Functions**

- ISS Communications Interface
 - 1553 Interface
- High Speed Data Link (HSDL) Interface
 - Fiber Distributed Data Interface (FDDI)
 - Ethernet 10/100
- Laser Communications/Control Interface
 - RS422 Interface
 - Verify Command
 - Shutdown Power/Laser

- **Features**

- DDC BU-63825G6-610 Mil-Std 1553 Protocol
- Space Photonics, FireFiber Transceiver
- Actel RT3PE3000L
 - FPGA 1553 Control Interface
 - FDDI Protocol

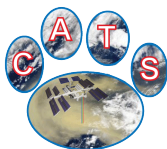


Comm: Connectors

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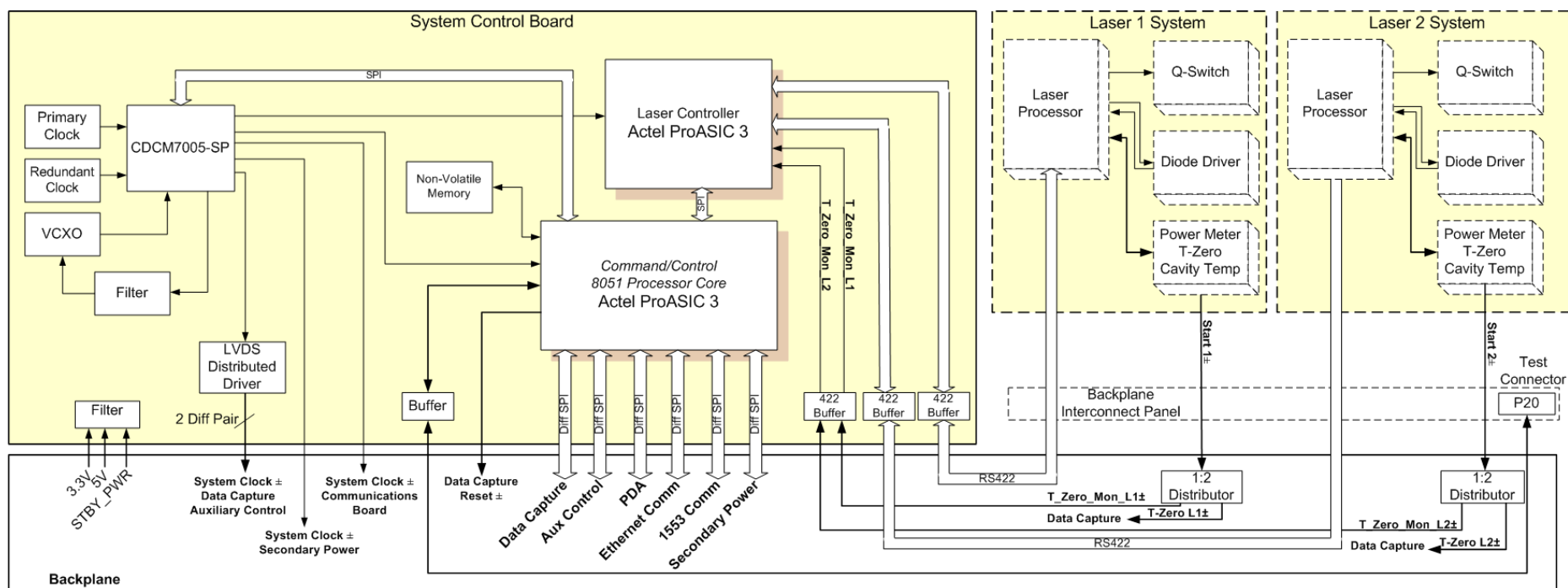
- Threaded MIL-STD 1553 A/B Connector
 - Trompeter BJ3450P
 - Twinax Bulkhead Jack, Rear Mount
- Ethernet Connector
 - MIL-DTL-38999 9-1 Shell
 - Size 10QX Quadrax Contact
- FDDI Optical Connector
 - Transmit Connector: Diamond AVIM
 - Receive Connector: Diamond AVIM

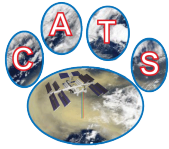




CB: Assembly

183





CB: Functions and Features

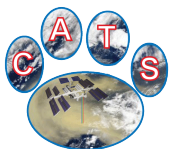
184

- **Functions**

- Principal Command/Control Interface
- Laser 1 and Laser 2 Control
 - Differential Serial Communications
 - Separate Comm. Link to each Laser
- Provides a system level clock that is distributed among the various boards.
- System Bus Interface
- Provides System Reset

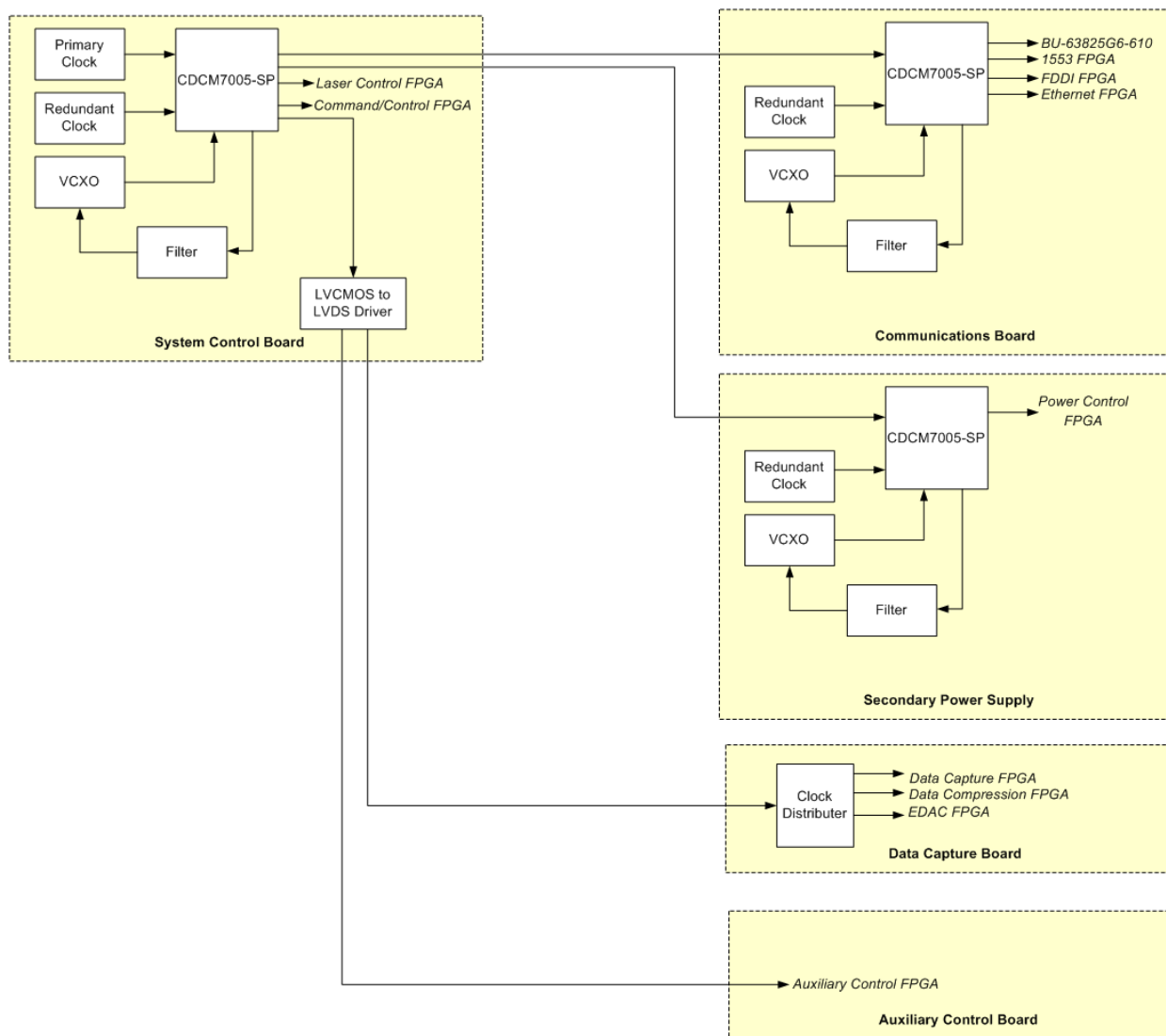
- **Features**

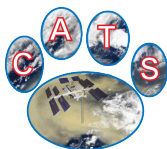
- Actel ProASIC 3 8051 Processor Core
- Redundant System Clock
- Non-volatile memory
- LVDS Distributed Driver
- Monitors the Laser T-Zero pulse.



CB: Redundant System Clock

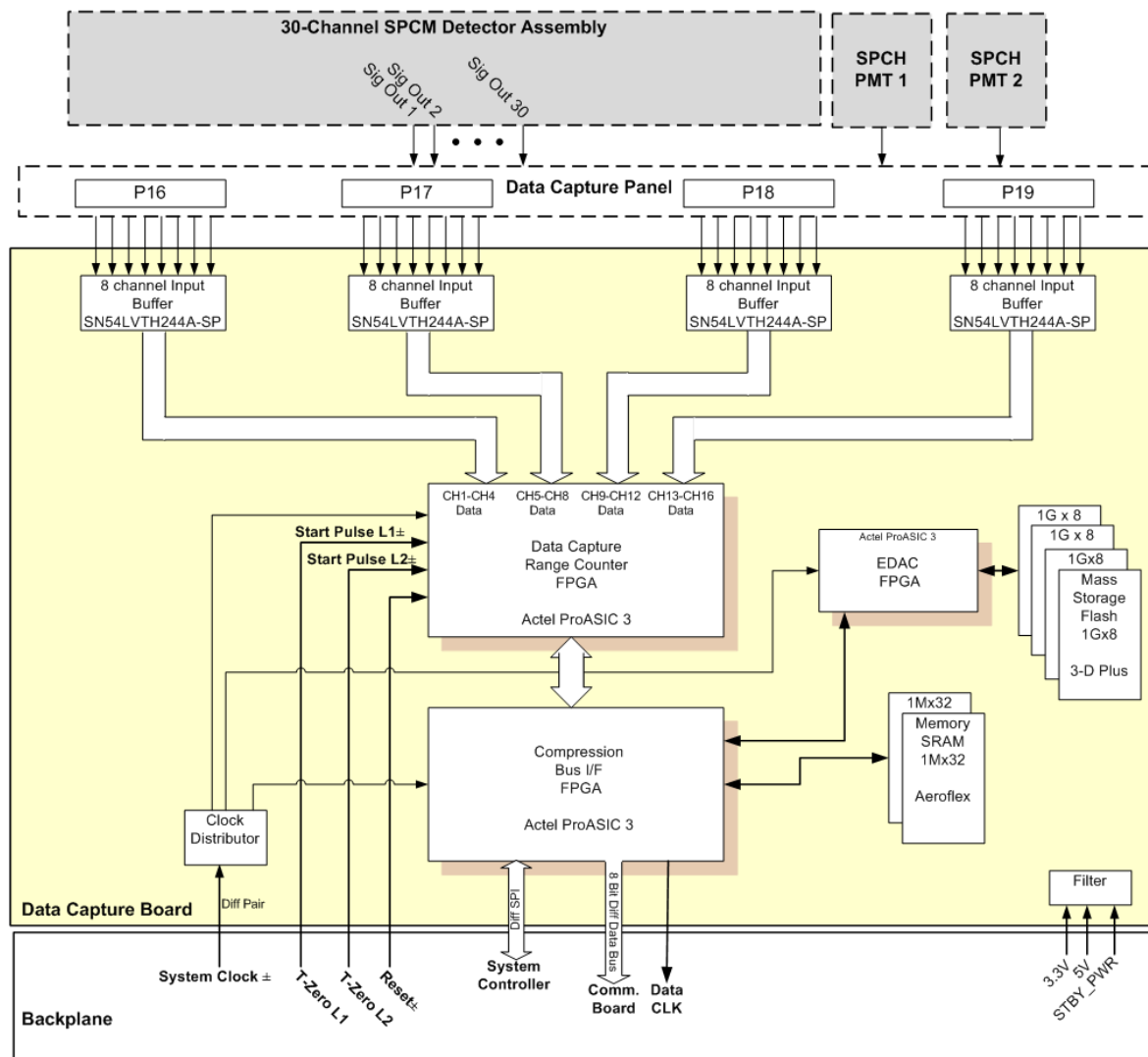
185

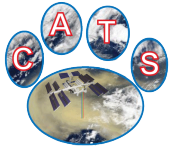




DCB: Assembly

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DCB: Functions and Features

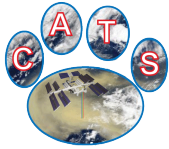
187

- **Functions**

- Receives data from the Receiver Detector Array
 - 30 SPCM APD Detectors
 - 2 PMT Photon Counting Heads
- Data Compression
- Error Detection and Correction (EDAC)

- **Features**

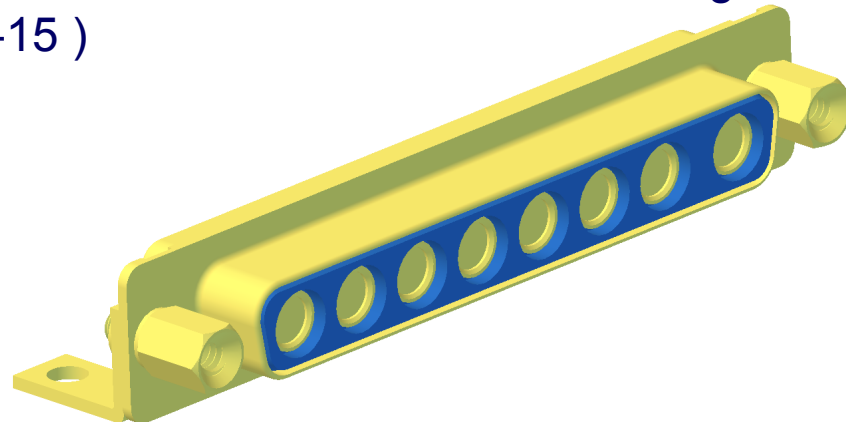
- Data Capture/Range Counter FPGA
 - Actel ProASIC 3
- Memory
 - 4 M words Hi-Rel SRAM onboard memory
 - Backup Flash
- All Logic Synchronized to the System Clock
- Range count start pulse comes directly from the Laser T-Zero
- Oversamples incoming pulses

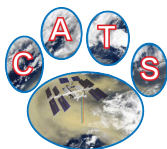


DCB: Panel Connectors

188

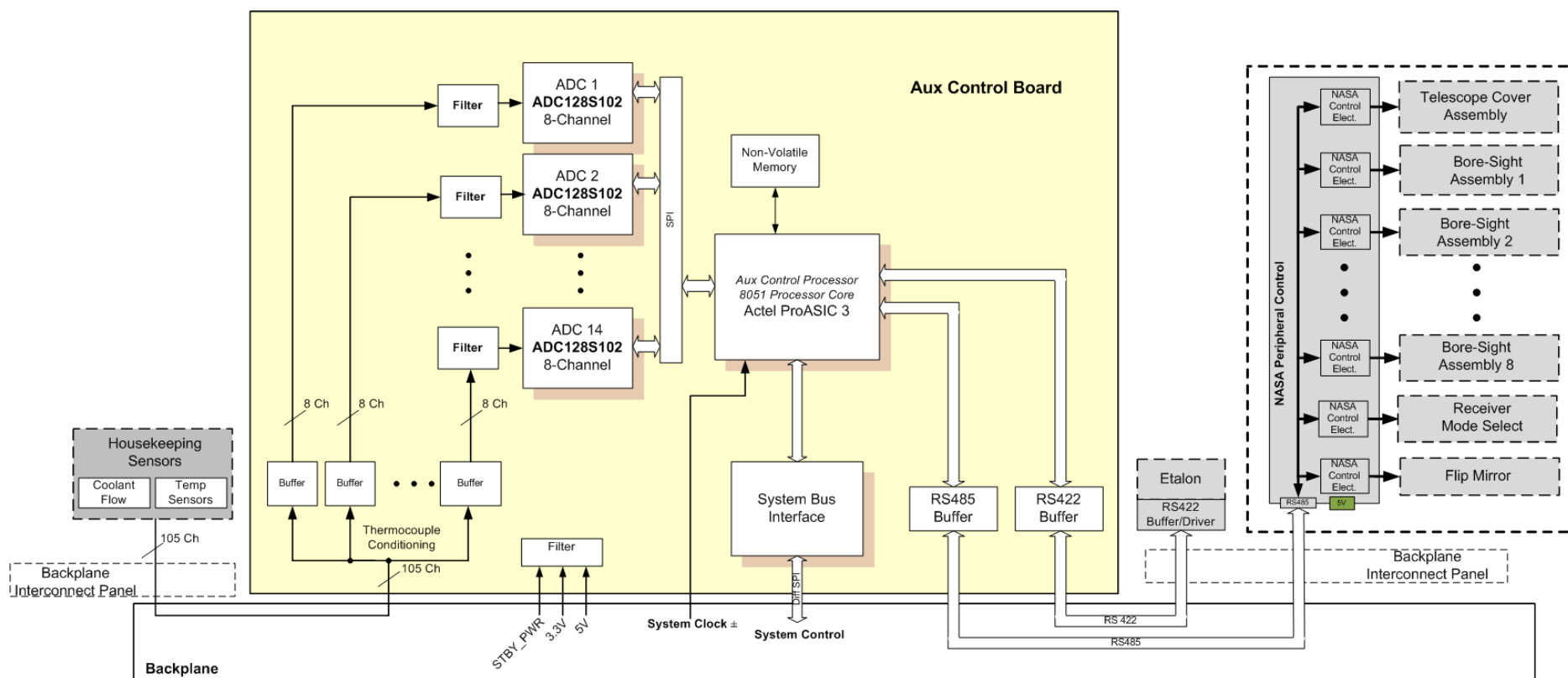
- **The Data Capture Board will use four 8W8 combo coaxial DSUB Connectors (32 Coax inputs) to connect to the detector arrays.**
 - Cable mount from panel to board.
 - RG316 B/U Compliant
- **Panel Connector (Shown Below)**
 - Shell: GSFC 311P10-15S-B-12
 - Receptacle Contact: GSFC S-311-P-4/06 PIN Designation GCS2 (ITT Cannon DM53742-16)
- **Cable Connector**
 - Shell: GSFC 311P10-15P-B-12 (ITT Cannon DCM-8W8P-NMB-77)
 - Plug Contact: GSFC S-311-P-4/06 PIN Designation GCP2 (ITT Cannon DM53740-15)

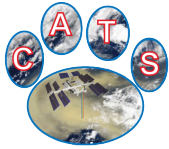




ACB: Assembly

189





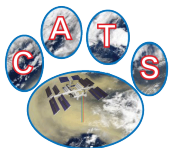
ACB: Functions and Features

190

- **Functions**
 - RS 485 Peripheral Control
 - Eight Bore-Sight Steering Optics Assemblies
 - Telescope Actuator
 - Flip Mirror Motor
 - Mode Select Motor
 - Etalon Control
 - Differential Serial Communications
 - Supports and Processes all Housekeeping functions
 - Preconditions thermocouple sensors to provide a temperature related voltage
 - Thermocouple A-D Conversion
 - Temperature Monitoring & Feedback Functions
- **Features**
 - Actel ProASIC 3 8051 Processor Core
 - Non-volatile memory
 - Fourteen 8 Channel, A-D Converters
 - System Bus Interface
 - RS485 and RS422 Buffers

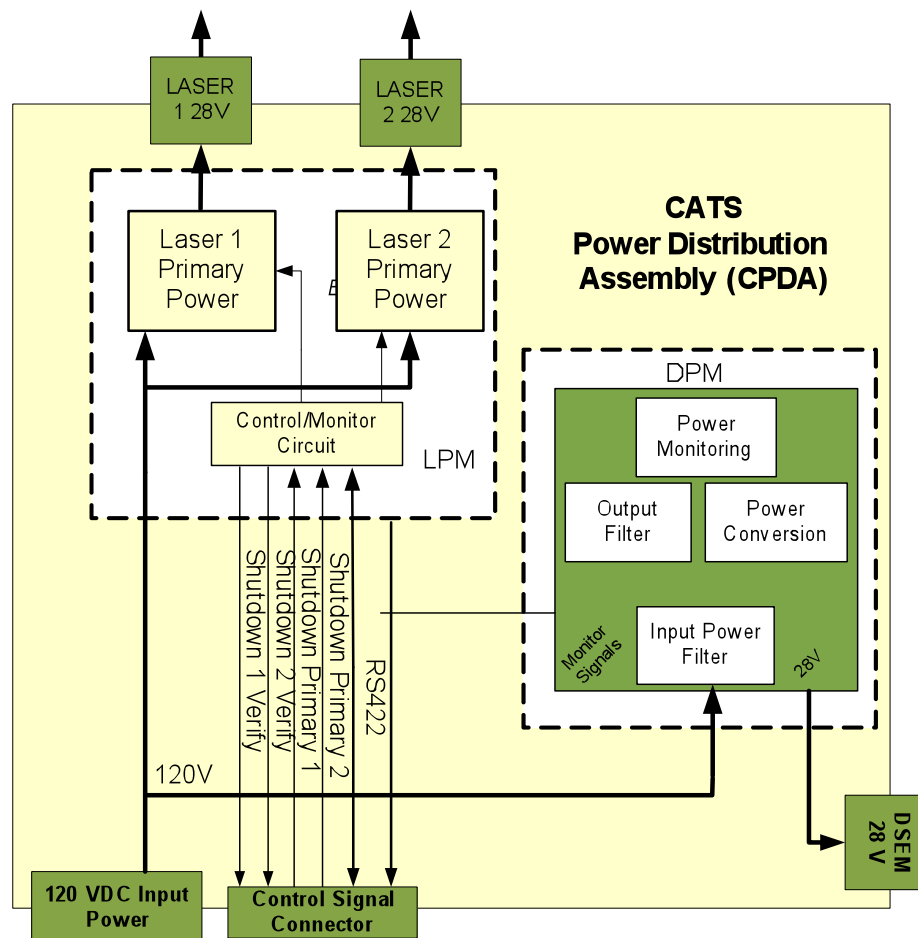


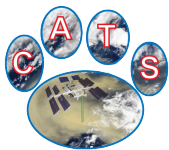
Power Distribution Assembly



PDA: Assembly

192



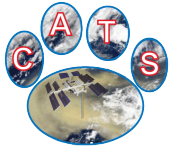


PDA: Main Power Supply

193

- Provides 28 VDC to laser units and DSEM
- Aluminum Chassis and Cover
 - Volume 11" x 9" x 5"
 - Attaches to cold plate for thermal management
 - Vented box





PDA: Functions and Features

194

- **Functions**

- Receives 120VDC power from JEM-EF power bus
- Primary power for DSEM, Laser 1 & Laser 2
 - 28VDC
- Circuit protection
- Temperature and power monitoring sensors

- **Features**

- 11"x 9"x 5" footprint
- Uses efficient resonant topology design



PDA: 600W Demonstrator Board (non-flight)

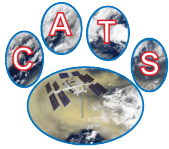
195



- Uses Resonant topology (LLC) to maximize efficiency and MOSFET reliability
- Relatively easy transition to flight qualification (TI UC1863 control IC)
- Dimensions are: 9" x 5" x 2"



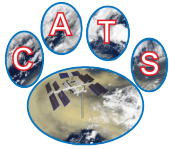
Summary



DSEM Safety Summary

197

- Two Independent Shutdown Methods
 - Each individual Laser primary supply has a dedicated shutdown input discrete and a corresponding shutdown verify output discrete.
 - Each Laser has a dedicated Shutdown discrete to its individual diode driver supply.
 - All safety shutdown discrete controls are hardwired directly from the data command packet.
- Redundant Verification Features
 - Two Independent Verification Circuits
 - All safety verification discrete signals are hardwired to the data status packet.
 - Each discrete verification signal reports to a different communications link.
 - Ethernet/FDDI as part of the data packet
 - 1553 BUS as part of the status return packet
- Software Command Verification
 - Safety conditions can be verified via a software status request.
- Both the SPS and the Comm. Board have additional clock redundancy.

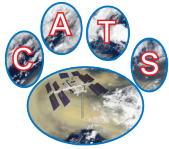


- **Risk #1 – HSDL Technology**
 - FDDI: Lack of information on physical layer, test verification methods not defined
 - Technical Impact: Moderate
 - Schedule Impact: Moderate
 - Cost Impact: Moderate
- **Risk #2 – Requirements Definition**
 - Aggressive schedule using Hi-Rel components necessitates early requirements definitions
 - Technical Impact: Moderate
 - Schedule Impact: Moderate
 - Cost Impact: Moderate



I&T and GSE

Matt McGill and Stan Scott



I&T Considerations

201

- **Facility**
 - CATS will be built in B33 Rm D409.
 - Environmental testing will be done off-site at contract facilities.
 - Additional testing required at launch site (functional and alignment).
- **Laser operations**
 - CATS lasers are Class 4, having potential for eye injury.
 - During laser testing, beams will be enclosed/terminated.
 - During instrument testing output beam ports have eye-safe filters installed.
 - Lab facility will be certified for laser operations.
 - All laser operators will be laser safety certified.
- **Contamination control**
 - Lab facility will be Class-10,000 certified.
- **ESD control**
 - Lab facility will be ESD certified.

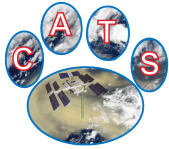


I&T Facility

202

CATS facility, B33 Rm D409
“932 sq. ft. of blinding white cleanliness”

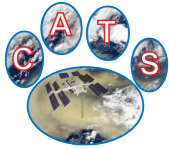




I&T Verifications

203

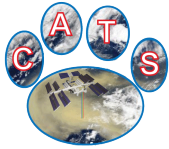
- **Functional and performance tests**
- **Alignment and calibration**
- **EMI/EMC**
 - required by ISS
 - will be done at MetLabs
- **Vibration (sine-sweep, random)**
 - required by ISS
 - will be done at MetLabs
- **Thermal-vacuum**
 - required by ISS
 - will be done at MetLabs
- **Acoustic testing** not required or planned.



Configuration Management Approach

204

- **Verification plans are required by ISS, most already in draft form (structural verification, fracture control, etc).**
- **Materials list maintained, approved by GSFC materials branch, and provided to ISS.**
- **Work Order Authorizations (WOAs) will be used for all steps of manufacturing, assembly and test.**
- **WOAs, certifications, drawings, and associated paperwork retained for official documentation.**
- **All personnel properly trained:**
 - **electrostatic discharge (ESD)**
 - **laser safety (as required)**
 - **cleanroom use**

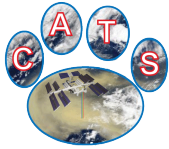


Ground Support Equipment (GSE) will be developed:

- transport cart
- eye safe filters
- LTR for alignment testing at launch site
- electrical GSE

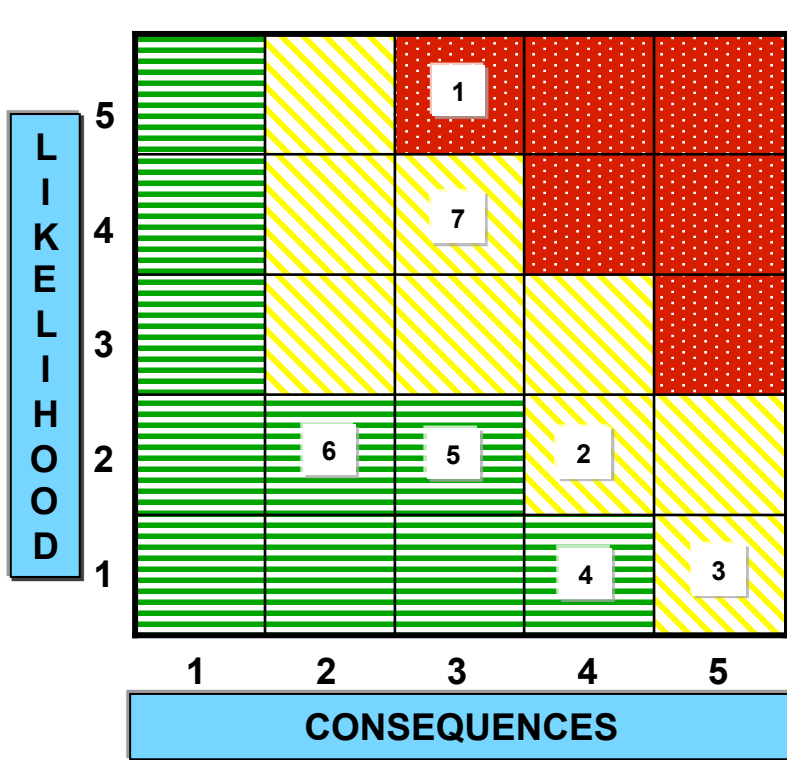
Some GSE is provided by JSC/ISS:

- PIU Adapter Unit for electrical testing
- coolant cart for testing coolant loop
- ISS simulator (STEP)



Risk Matrix

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Trend	ID	RAC (LxC)	Approach	Risk Title
➡	1	15	W	Schedule, due to launch vehicle selection
➡	2	8	W	Telescope delivery
➡	3	5	R, M	Detector vibration testing
⬆	4	4	M	Payload mass
➡	5	6	W	Laser delivery
⬇	6	4	R, M	Thermal limits
➡	7	12	R	Additional "unknown" ISS requirements

Criticality



Consequences:

5 - Neg margin/Slip launch/Mission Obj. not met
 4 - No margin/Major schedule slip/Some Miss. Obj. not met
 3 - Sign. Margin reduction/Schedule slip/Some Mission Obj. not met
 2 - Some margin reduction/Additional resources needed/Mission Obj. degraded
 1 - Negligible - Minimal or none

Likelihood:

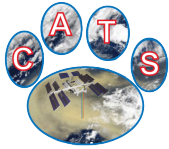
5 - Likely: Probability > 10%
 4 - Probable: Probability 1% - 10%
 3 - Possible: Probability 0.1% - 1%
 2 - Unlikely: Probability 0.0001% - 0.1%
 1 - Improbable: Probability < 0.0001%

L x C Trend

⬇ Decreasing (Improving)
 ⬆ Increasing (Worsening)
 ➡ Unchanged

Approach

M - Mitigate
 W - Watch
 A - Accept
 R - Research



Review Summary

207

- This is a spectacular opportunity, and we have been given wide latitude to generate good science.
- Team is staffed and stable*.
- Instrument design and requirements are consistent with the [self-generated] science requirements.
- Preliminary engineering trades are complete, and are consistent with schedule, cost, and ISS safety requirements.
- Adequate margins on mass, power, etc. (volume is pre-defined and inviolable).
- Safety and ISS/JSC requirements in good shape.
- Schedule and budget are aggressive, but no insurmountable issues identified.

*not mentally



This concludes the review.

**Thank you very much for your time
and participation.**